Civinnovate

Discover, Learn, and Innovate in Civil Engineering

1. Introduction to Transportation Planning and Engineering (4 hrs)

1.1 Introduction
1.2 Modes of Transportation
1.3 Comparison between various modes of Transportation
1.4 Historical Development of Roads: Roman, Tresaguet, Telford, Macadam
1.5 Road Construction in Nepal
1.6 Transportation Planning including Objectives of Planning
1.7 Classification of Roads: Strategic Road Network, Rural/Local Road Network, Urban Road

1.1 Introduction to Transportation System

A transportation system may be defined as consisting of the fixed facilities, the flow entities, and the control systems that permit people and goods to overcome the friction of geographical space efficiently in order to participate in a timely manner in some desired activity.

The transportation system as defined by ITE-Institute of Transportation Engineers can be summed up as the application of technology and scientific principles to the planning, functional design, operation and management of facilities for any mode of transportation to provide safe, rapid, comfortable, convenient, economical and environmentally compatible movement of people and goods.

Components of Transportation System

A transportation system consists of different components which together allow people and goods to overcome the hindrance of geography. The different components are:

1. **Fixed facilities**

These are the physical components of the system that are fixed in space and constitute the network of links and nodes. Road, railway track, ocean or waterways, airports harbor etc. are fixed facilities of their respective modes.

2. **Flow entities**

These are the components that traverse (travel through) the fixed facilities. They mainly include vehicles and are considered on the basis of shape, size, weight, acceleration and deceleration abilities. For example, road vehicles, trains, aircraft, ships etc.

3. **Control system**

This system consists of vehicle control and flow control.

Vehicle control refers to the technological way in which the vehicles are guided either automatically or manually. Flow control consists of the means that permit the efficient and smooth operation of stream of vehicles and the reduction of conflicts between them. Eg: traffic control using traffic lights, at the intersection, road signs and markings, air traffic control etc. help in the smooth flow of vehicles.

Role of Transportation in Society

Transportation is an inseparable part of a society. In fact, the measure of the development of any society is characterized by how developed transportation system is. Advancement in transportation has made a vast change in the quality of life of people. Impact of transportation can be summarized as below:

1. **Economic role**: Transportation plays an important role in developing the economic aspect of a society. Economics involves production, distribution, and consumption of goods and services which are inevitable without the transportation facility. In a country like Nepal which has a wide gap between production and consumption, an effective mode of transportation can always be helpful for its economic growth. Rice of terai need to be transported to the hills and the apples of Humla and Jumla need to be brought up to the terai.
2. **Social role**: Development of transportation system influences the formation of urban society. It links rural areas with urban ones transporting goods from one place to other, eventually helping in overall development. Transportation also promotes cultural and social exchanges. It provides employment opportunities.
3. **Political role**: The world being divided into different political units for mutual protection, economic advantages and development of common culture is linked by transportation of both people and goods through different modes. Transportation plays a vital role in functioning of these political units.
4. **Environmental role**: The environment is highly affected by transportation. Its harmful aspect is more prominent than its useful aspects. Air pollution, noise pollution, overuse of non-renewable energy etc. are some of its impacts on the environment. Transportation safety (mainly road safety) is of major concern.

1.2 Modes of Transportation

a) Primary Mode
- Land Transportation (Highway, Railway)
- Air Transportation
- Water Transportation
- Pipeline Transportation

b) Secondary Mode
- Ropeway
- Belt conveyors
- Canal

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Primary Mode

Land Transportation

1. **Highway**: The major advantage of the highway is that it has high accessibility to almost all potential destinations, direct service with very low door-to-door travel times, moderate speeds and capacities. Capital cost for physical facilities is also moderate. Vehicles are small and readily available at a low cost. However operating cost tends to be higher. Environmental impacts of the system as a whole are high and are a major social concern.

2. **Railway**: The railway system provides moderate speeds and levels of accessibility. Accessibility is only limited to railway stations. A heavy capital must be invested in both physical facilities and flow entities. This mode is very effective for transportation of a lot of goods through land.

Air Transportation

The main advantage of air transport is its high speed and less time consumption. Accessibility is limited but is of less importance as greater lengths of trips are made. Capital investment as well as operating and maintenance cost for both fixed and flow entities are higher than other modes. Environmental impacts are significant, air and noise pollution of commercial aviation but are of less concern than that of highways.

Water Transportation

Water transportation provides low speed and relatively low accessibility, but extremely high capacities. The capital cost of vehicles, especially ships are very high but operating cost is low for a large distance. So, if a lot of goods is required for transportation, this mode can be used for best results. Environmental effects are relatively low but the chances of water pollution due to leakage of oil and petroleum products are high.

Pipeline Transportation

The transport of daily use products and wastes to the desired location encompass pipeline transportation. They provide very low speed, but the high capacity constant flow and involves a large amount of working storage. Environmental impacts are generally low.

Secondary Mode

A variety of other modes also exists although they do not contribute in major transportation, however, are inevitable.

Ropeway refers to special type of carriers suspended from or simply attached to an overhead rope. Ropeway is an effective, economic and environmentally friendly way of crossing hills. Belt conveyors are belt supported on rollers that provides steady movement of materials. Cable and belt are systems extensively used in industries for transportation of goods. Canals are also used in transportation for irrigation system in rural areas.

In the Context of Nepal

Nepal is a landlocked country. The possibility of waterways is less due to the presence of fast flowing rivers. So, water transport is only limited to small distances for fishing and crossing the rivers. Also, most of the area is covered by hills and mountains. So, the potentiality of any mode of transport becomes less. But road transport is the best option Nepal has carried out so far. However, there is a lot of potential for ropeways and railways. Although it is difficult to provide railways at every place it can be a useful mode of transport. The government of Nepal has established a Department of Railways giving more priority on the development of railway tracks. Similarly, ropeways program is also being started at different places in Nepal.

1.3 Comparison between Various Modes of Transportation:

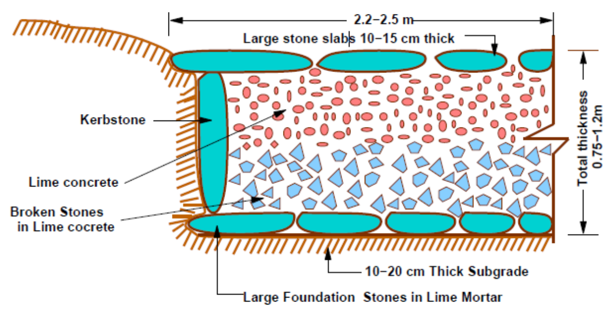
	Roadway	Railway	Airway	Waterway	Pipeline
Accessibility	High	Moderate	Low	Low	Low
Speed	Moderate	Moderate	High	Low	Very Low
Capacity	Moderate	Higher than roads.	Capacity per vehicle is limited.	High capacity per vehicle.	High capacity.
Initial Capital Cost	Moderate	High	High	High	Moderate to High
Operating Cost	High	Moderate to High	High	Low	Low (Depends mainly upon pumping cost).
Efficiency	Not high	High	Low	Very High	High

1.4 Historical Development of Roads:

- The first mode of transportation was by foot. This led to the development of footpaths.
- The next major mode was the use of animals. This led to the development of trackways as the loaded animals required more horizontal and vertical clearances.
- The invention of wheel in Mesopotanian civilization led to the development of animal drawn vehicles. Then it became necessary that the road surface should be capable of carrying greater loads. Thus, roads with harder surfaces emerged.

1. Roman Road

- Romans constructed an extensive system of roads radiating in many directions from Rome.
- Romans recognized that the fundamentals of good road construction were to provide good drainage, good material and good workmanship.

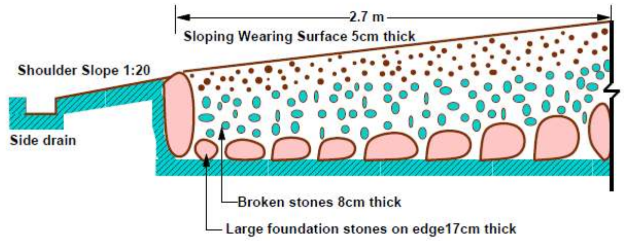


- Roads were constructed on a firm-ground subgrade strengthened where necessary with wooden piles.
- Roads were bordered with longitudinal drain.
- **Construction of Agger:**
  - Raised formation upto 1m high and 15m wide.
  - Constructed with materials excavated during side drain construction.
  - This was then topped with a sand levelling course.
  - Agger contributed greatly to moisture control in the pavement.
  - In case of heavy traffic, a surface of large 250mm thick hexagonal flag stones were provided.
- **Main Features:**
  - Built regardless of gradient.
  - Used heavy foundation at bottom.
  - Mortar made from lime and volcanic pozzolana and gravel added to make concrete.
  - Concrete was a major Roman Road making innovation.

The roman road network built during seven centuries extended over a total length of 90000 km. of which about 14000 km still exist in present day.

2. Tresaguet Roads (French Roads)

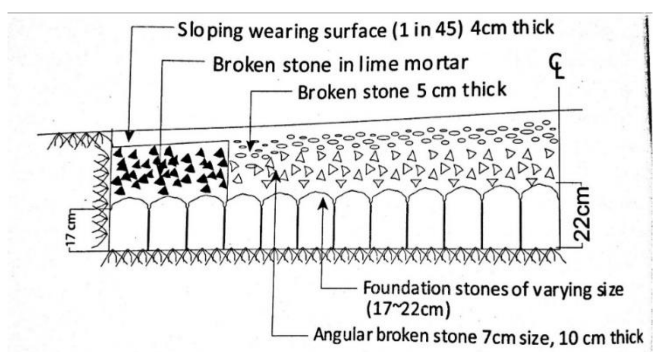
- The next major development in the road construction occurred during the regime of Napolean.
- Contributions were given by Tresaguet in 1764 and was implemented in 1775.
- He developed a cheaper method of construction than the lavish and locally unsuccessful revival of Roman practice.



- Pavement used 200mm pieces of quarried stone of a more compact form and shape such that they had at least one flat side which was placed on a compacted formation.
- Small pieces of broken stones were than compacted into spaces between large foundations to provide a level surface.
- Running layer with 25mm sized broken stone was made.
- All this structure was placed on a trench to make running surface in level with the surrounding country side.
- Drainage problems was counteracted by making the surface as impervious as possible, cambering the surface and providing deep side ditches.

3. Telford Construction

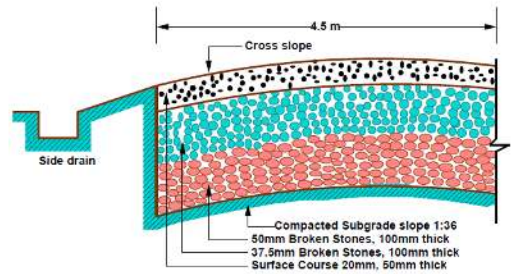
- Telford in England (1757-1834) proposed similar type of construction as Tresaguet in France.
- Slopping surface on the top was achieved by providing varying size of stones in foundation.
- For lateral confinement, Telford used a block made of broken stones in lime water.



4. Macadam Construction (British Roads)

- First scientific road construction method.
- Economical method of road construction.
- Stone size was an important element of macadam road construction.
- John Macadam (1756-1836), a Scottish road builder, is considered as the *pioneer of modern road construction*. Macadam came to realize that 250mm layers of well

compacted broken angular stones would provide the same strength and stiffness and a better running surface than an expensive pavement founded on large stone blocks.



- The mechanical interlock between the individual particles provided strength and stiffness to the course.
- Inter particle friction abraded the sharp interlocking faces and partly destroyed the effectiveness of the course.
- The effect was overcomed by introducing good quality interstitial finer material to produce a well-grained mix.
- Such mix proved to be less permeable and easier to compact.

5. **Modern Roads**
   - Follows Macadam's construction method.
   - Uses bituminous concrete and cement concrete.
   - Various advanced and cost-effective construction technologies are used.
   - Development of new equipment helps in the faster construction of roads.
   - Easily and locally available materials are tested in laboratories.

1.5 Road construction in Nepal:

- 70,000km distance road is constructed in Nepal.
- Local roads contribute to distance more than 52000km.
- Headquarters of Dolpa and Humla are not connected with roads.
- 400 villages are devoid or roads. 15000-20000km roads are to be constructed to overcome this.
- Out of Bhaktapur, Kathmandu and Lalitpur, Bhaktapur is highly fascilated with roads.
- 60% of National Highways are black topped.
- 40-50% of Feeder roads are black topped.
- Total SRN Length: 12898.20km
- Total Population: 26620809
- Total Area: 147181 sq.km.
- Population influenced per km. roads (Nos.) = 2064
- Road Density (km/100 km^2) = 9

1.6 Transportation Planning Including Objective of Road Planning

Transportation system requires a continuous planning to optimally satisfy the mobility requirement of the society. Planning becomes significant when the resources available are limited and requirements are higher. The main objective of planning is to optimally utilize the available resources in the best possible way and in a very systematic manner.

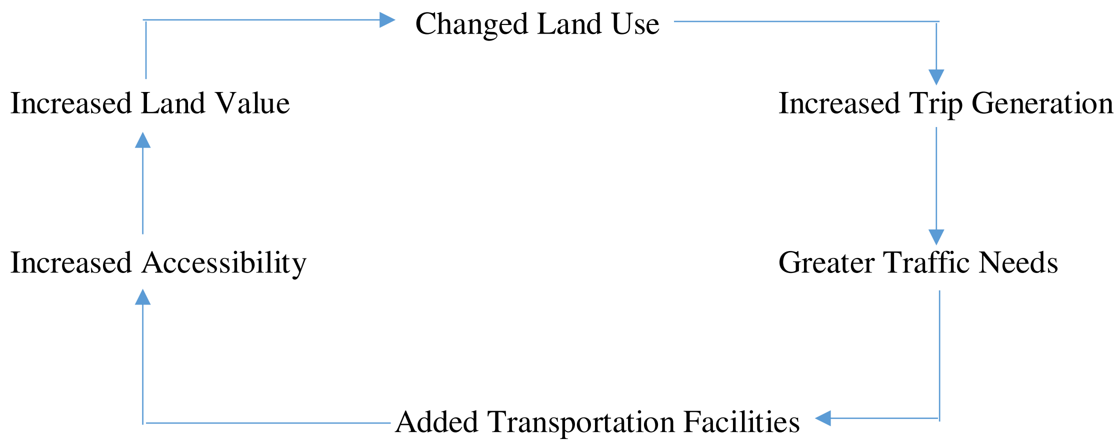


Fig: The land use Transportation Cycle

Types of planning

Transportation planning can be divided into short term, medium term and long-term planning.

Short term (1-3 years) and *medium-term (3-5 years)* planning can be defined relatively in the same way. They are less complex and put no great demand on construction activities and require less capital expenditure. It includes Transportation System Management (TSM).

Long-term (More than 5 years) planning is a complex problem and requires huge financial expenditure and involves large and extensive construction programs which affect the environment in economic, social and natural aspects.

Desired solution is obtained through carefully constructed policy making at the multi-levels of government and administration involved which could be solved best through system approach.

The System Approach

The system approach is a decision-making process for complex problem solving composed of:

- **System analysis:** A clear evaluation of the combinations of all the elements that structure the problem and those forces and strategies needed for the achievement of an objective.
- **System engineering:** Organizing and scheduling complex strategies for problem-solving. It includes:
  - Identifying the problem
  - Tackling the problem considering all facets
  - Use of scientific methods
  - Working as per predetermined sequence
  - Scientific decision

In dealing with long term transportation planning, three basic elements should be considered:

a) Forecasting demand
b) Description of economic, social and environmental changes
c) An evaluation of the system in term of benefits and dis-benefits

The planner should continuously deal with three different groups having their own vested interest namely operators, users and non-users.

- The operator is concerned with capital costs, operating costs, operating revenues and the viability of the plan.
- The user is concerned with monetary cost, journey time, safety and security, reliability and comfort and convenience.
- Large number of people who neither travels nor causes goods or people to move are also affected by the proposals of the transportation planner. Such non-users are affected by land use changes, social disruption and economic effects.

Land Use-Transportation Model

Land use transportation model is an effective way to study and design transportation plans. The land use-transportation model can be studied under two phases: *calibration phase* and *projection phase.* The calibration phase is followed by projection phase. In the calibration, phase models are built and tested using data from a base period and in the projection phase, the developed model is used to determine future transport design based on socio-economic projection for a design year.

Road Plan/Highway Plan

National Plan
↓
National Transport Plan
↓
Regional Transport Plan
↓
Local Transport Plan

Fig: Hierarchy of Road Transportation Planning

<u>Objectives of Road Planning</u>

1. **To establish an integrated network of road:**

An integrated highway network capable of accommodating all highway travel in an orderly, safe, efficient and economical way is required. Hence highway development plan is an essential part of national transport plan. For this following three processes should be followed:
-Forecast the future requirement of roads needed.
-Set up priorities and schedules of construction and renewal program in accordance with the available resources.
-Financial planning and management.

2. **To fulfill the needs of the society:**

Road planning is basically accepted as an outcome of the needs of the society. The first step in planning is to identify all the present as well as the future need of the society. These needs are to be fulfilled in the second step of planning.

Road planning can be grouped as:

National Road Network Planning

It is the planning of all roads to be developed in the national context and includes:

- National Highways
- Feeder Roads

Nepal's national road network plan is in the form of the linear pattern with the dead ends on hill district headquarters. National highways run east to west and north to south to which feeder roads or district roads are connected to link district headquarters and major cities, towns, villages etc.

Urban Road Network Planning

Urban areas must be developed in a sustainable way so that the development remains intact for many years. So, planning of road networks in urban areas is an integral part of its development.

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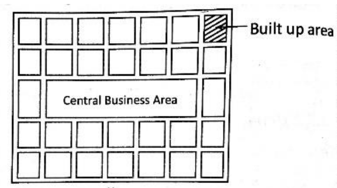
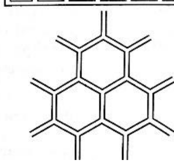
The major road patterns developed in modern urban areas are as follows:

1. **Grid Iron Pattern**
- **Rectangular or block**
- **Hexagonal**

2. **Radial Pattern**





Grid Iron Pattern

In grid iron pattern the built-up area is obtained in a rectangular or hexagonal shape. It can produce monotonously long streets and dull blocks of the building. However, it encourages even spread of traffic over the grid and as a consequence, the impact at a particular location is reduced.

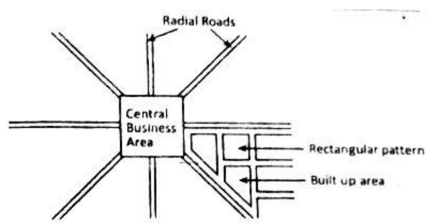
<u>Advantages</u>

- Low cost
- Simple to plan
- Gives good circulation plan and easy for plots subdivision.
- Efficient in providing drainage and sewerage network

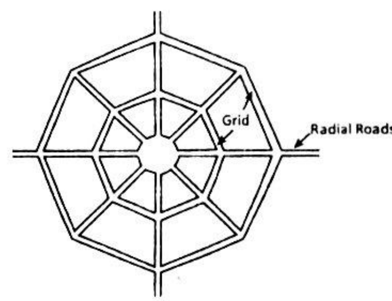
<u>Disadvantages</u>

- Offers limited urban design options
- Produces constrained and rushed psychological effect
- Can be confusing and frustrating.

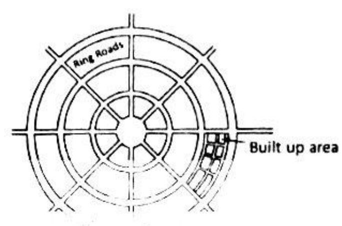
Radial Pattern



This system is widely used in many countries to join one town centre to another town centre. Thus, any given town may have several roads radiating from its centre to other towns and villages around it. As towns grow in size, they turned first to develop along the radial direction and fill in the spaces after that. The main traffic generator is located within the centre area and all radiating roads converge on the main business area of the focal point.



Ring Roads:



- Ring road is a radial pattern of road which runs in circumference to an urban area so as to avoid excess traffic inside the area.
- There may be doubling or tripling of rings depending upon the size of the urban area and requirement of population.

- Due to ring roads there is a direct access to the to the town centre. The town centre may be a core business area and may have banks, shopping complexes, entertainment centers etc.
- In Kathmandu, an inner ring road is already built. Due to the increasing population and increase in no. of vehicles, an outer ring was proposed and now is in construction phase.

Road Transport

Road transport is one of the common, efficient and accessible modes of transport.

Advantages of Road Transport:

- **Wide geographical coverage:** It covers a large area and can penetrate the interior of any region to connect remote places.
- **Large influential area:** Development of other modes of transport is only limited to target areas whereas road network can help in the economic and social development of almost all the areas it passes through.
- **Low capital investment**
- **Flexibility:** Road transport offers most flexible service to the passengers. Other modes like railway and airways have a fixed schedule which cannot be changed according to the demand.
- **Quick and assured deliveries:** Road transport offers quick and assured deliveries. Articles like milk, meat, vegetables and other perishable items can only be transported through roadway. It provides easy and efficient handling of these materials in an uneconomic way.
- **Highest employment opportunities.**
- **Low cost of packaging:** road transport involves very less handling process so the cost of packaging of goods is effectively lessened.
- **Economy:** It is economical for short distance travelling.
- **Safety:** It has less disastrous effect than other modes.

Disadvantages of Road transport

The disadvantages of road transport are:

- Land coverage: Roadways tend to use up more land. It destroys agricultural land and natural terrain. There is a chance of soil erosion, damage of forests lands and other physical structures if not properly constructed.
- Environmental Pollution: Compared to other modes it is one of the main cause for air pollution. Use of bitumen during construction also affects the environment.
- Poor safety records.
- Uneconomical for long distances

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Highway engineering and its scope:

The science which deals with the planning, design, construction, operation, and maintenance of roads and roadway facilities for the convenience of road traffic is known as Highway Engineering. The scope of highway engineering can be listed as:

- Highway development, planning and location.
- Highway design: geometrics, structure, hydraulic design of drainage system pavement.
- Highway construction materials, equipment, technology.
- Highway maintenance.
- Traffic operation and its control
- Roadside development and landscaping.
- Highway finance economics and administration.

1.7 Classification of Roads: Strategic Road Network, Rural/Local Road Network, Urban Road

According to Nepal Road Standard (NRS) 2070, roads in Nepal are classified as:

Administrative classification:

According to this classification roads are classifsied as:

- National Highways
- Feeder Roads
- District Roads
- Urban Roads

National Highways: These are main roads connecting east to west and north to south of the country. These roads shall be the main arterial routes passing through the length and breadth of the country as a whole. They provide consistently higher level of service in terms of travel speeds. They are designated by letter 'H' followed by a two-digit number.

Feeder Roads: These roads connect district headquarters, major economic centers, tourism centers to national highways or other feeder roads. They are designated by letter 'F' followed by three-digit number.

District Roads: Important roads within a district, serving areas of production and markets and connecting with each other or with the main highways are district roads.

Urban Roads: Urban Roads are the roads serving within the urban municipalities.

According to the hierarchy of travel movement urban highway can be classified as:

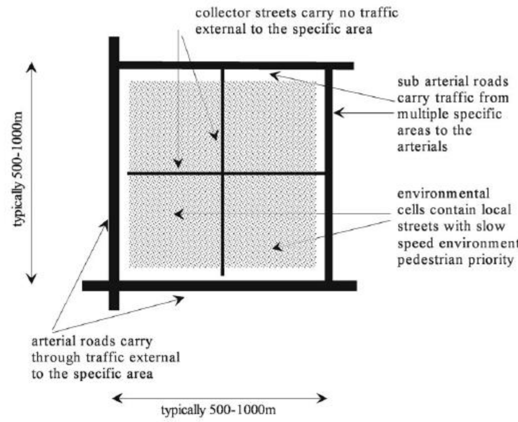
Expressway: They are divided arterial highways for vehicular traffic with full or partial control of access and provides grade separated intersection.

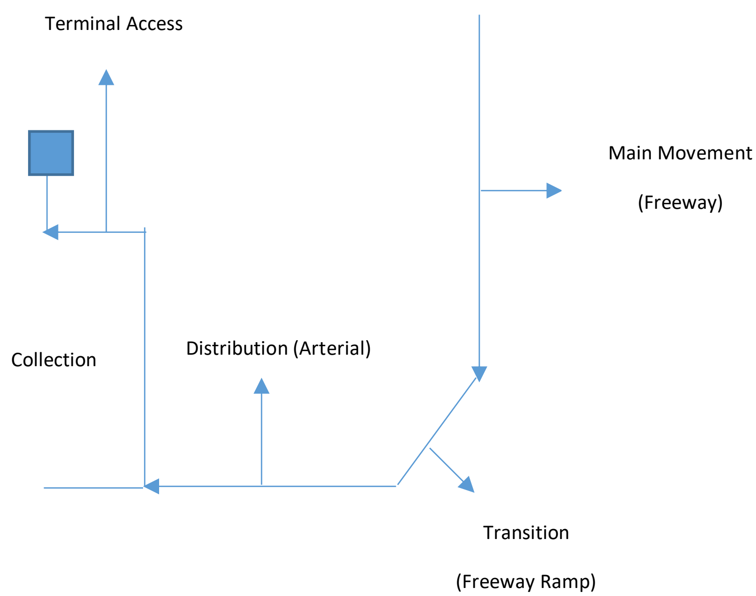
Arterials: They carry through traffic external to the specific area.

Sub-arterials: They carry traffic from multiple specific area to the arterials.

Collector: They provide indirect and direct access for land users within specific area.

Local Streets: They provide direct property access.





In Nepal the overall management of National Highways and Feeder Roads comes within the responsibility of the Department of Roads (DOR). These roads are collectively called *Strategic Roads Network (SRN*) roads. District Roads and Urban Roads are managed by Department of Local Infrastructure Development and Agricultural Roads (DOLIDAR). These roads are collectively called *Local Roads Network (LRN)* roads.

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Technical Classification:

	Design Speed(km/hr)	ADT in 20 years prospective period (pcu)
Class - I	120	>20,000
Class - II	100	5000-20,000
Class - III	80	2000-5000
Class - IV	60	<2000

PCU- Passenger Car Unit.

For the design of roads, the class of road is taken as the basic deciding factor which is ascertained based on the traffic volume on the road. But an approximate correlation can be established between the administrative and functional classifications of the roads as follows in the table below:

	Plain and Rolling Terrain	**Mountainous and Steep Terrain**
National Highway	I, II	II, III
Feeder Roads	II, III	III, IV

Rural Road Classification

District Road Core Network (DRCN): An important road joining a VDC HQ's office or nearest economic centre to the district headquarters, via eithera a neighbouring district headquarters or the Strategic Road Network.

Village Road: Smaller roads not falling under District Road Core Network category are Village Roads, including other Agriculture Road.

Reference:

Khanna, S., & Justo, C. *Highway Engineering.* Nem Chand & Bros, Roorkee.

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Nepal Road Standard 2070

Nepal Rural Road Standard 2071

IIT Lecture Notes

Highway Alignment and Engineering Survey (4 hrs)

2.1.1 Introduction:

The position of the center line of the highway in the ground is called highway alignment. Highway alignment includes horizontal alignment and vertical alignment. The projection of highway alignment in horizontal plane is called horizontal alignment and the projection in vertical plane is known as vertical alignment. Alignment must be selected in such a way that the overall cost during construction, operation and maintenance is minimum. Road design outputs are in the form of following drawings:

Plan: Includes centre line, structures, Right of Way (ROW), carriage way, shoulders, side drain.

Longitudinal Profile: Soil Type, Depth of cut, Height of Fill, Side drain (Information on from which chainage to which chainage), Direction of flow in the drain.

Cross section: Ground Level, Formation Level, Super elevation, Area of Cutting and Area of filling thus computation of the volume and then cost estimation can be done.

2.1.2 Requirements of Highway Alignment:

The ideal alignment must have the following requirements:

- Safe (S)
- Easy (E)
- Short (S)
- Economical (E)
- Comfort (C)

The requirements can be memorized as **SESEC.**

Safe: The alignment need to be safe during construction, operation and maintenance especially at slopes, embankments and cutting.

Easy: The construction materials if present at the place of construction makes the construction easier. Similarly, it should be easy during the operation of vehicles with easy gradients and curves.

Short: The distance between the initial and final point need to be short so as to reduce the construction cost.

Economical: The alignment should be economical during construction, operation, and maintenance. However, if the construction turned out to be economical, the gradient may not be easy which in turns increases the cost of operation and maintenance. Similarly, if the vehicle operation is taken under consideration and is made economical, the construction cost becomes higher as the gradient and curves need to be easy.

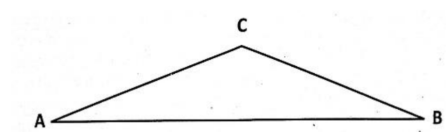
Comfort: The alignment should be fixed such that it provides comfort to the drivers and the passengers.

2.1.3 Factors Controlling Highway Alignment:

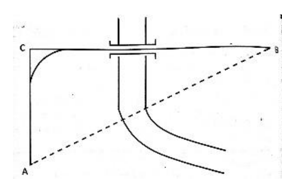
- **Governmental Requirement:** As the road project needs a large investment, the government should be clear about the requirement of the road (when, what, how and why to construct).

- **Obligatory Points:** Obligatory points determine the highway alignment. They are further divided into positive obligatory points and negative obligatory points.
  Positive Obligatory Points: These are those points through which the alignment should pass.

  - **Existing Road:** The alignment should be fixed such that the newly constructed road should link to the existing road. It reduces the cost of construction.
  - **Intermediate Town:** If there is the possibility of a straight road between point A and B and there lies the intermediate town at C as shown, then the road need to link the intermediate town reducing the change in highway alignment.



  - **Bridge site/Existing Bridge:** The road linking with the bridge must not be curved and to include the bridge in the road portion, the highway alignment may be changed.



  - **Mountain:** When the road has to cross a row of hills, mountain pass may be the suitable alternative.

  Negative Obligatory Points: These are those points through which the alignment should not pass.

  - Valleys, ponds, and marshy land need to be avoided.
  - Religious places are linked up with the human sentiment so cannot be destroyed for fixing the road alignment.
  - Costly structures present in the way of alignment should be considered and the road alignment should be fixed such that it won't destroy those costly structures as the value of compensation for such structures will be more.
  - Conservation areas and restricted zones.
  - Densely populated area.
  - The road should not be within the boundary of the country.

- **Traffic (Type, amount and flow pattern):**
  The alignment should be according to the traffic amount and flow pattern. The number of lanes can be determined as:
  Number of lanes = Traffic Volume / Traffic Capacity.
- **Geological Condition:**
  Geologically stable hill slope must be considered while selecting the highway alignment.
- **Geometric Design:**
  Various factors regarding geometric design as the radius of curve, sight distance, gradient determines the highway alignment.
- **Availability of construction materials and labor:**
  The construction works become easier and economical when the construction materials are near the place of highway alignment.
- **Economy:**
  The construction, operation, and maintenance work should be economical. So, highway alignment is selected keeping these things in mind.

- **Other Considerations:**
  Drainage: The alignment needs to be fixed such that the number of cross drainage structures are less.
  Political: Alignment need to be within the allocated territory.
  Monotony: Setting the straight alignment leads to monotonous driving. So a small bend is provided to make the driver aware and alert. The roads are designed as forgiving roads.

Special Consideration in Hill Roads:

- **Stability:** The road should be aligned with the hill side that is stable. Excessive cutting and filling may effect on their stability.
- **Drainage:** Adequate drainage facility need to be provided across the road and the number of cross drainage structures need to be less during construction.
- **Geometric Standards:** Geometric design parameters also effect on the construction of roads. Minimizing steep gradient, hairpin bends and needless rise and fall.
- **Resisting Length:** The ineffective rise and excessive fall should be minimum.

2.2 Engineering Survey and its stages:

- Map Study
- Reconnaissance
- Preliminary Survey
- Final Location and Detailed Survey

2.2.1 Structure of Route Selection Process:

Sequential Structure of Route Location Process

Region → Bands (8-16km) → Corridors (3-10km) → Route Strips (1-1.5km) → Alignments (30-50m)

The beginning and the end point is selected and the region is defined. The region is further studied in search of broad bands which are 8-16km wide. From these broad bands, the corridor is studied then the route strips and possible alignments are found out.

2.2.2 Engineering Surveys: Map Survey, Reconnaissance, Preliminary Survey and Detailed Surveys:

Map Study:

The study of the topographical map is done to find out the possible routes of the road. Following information are obtained from the map study:

- Alignment avoiding valley, ponds, lakes.
- When the road has to cross a row of hills, mountain pass may be the suitable alternative.
- Approximate location of the bridge site.

Reconnaissance Survey:

Simple Survey Instruments are used in the reconnaissance procedure.
Following are the information obtained from the reconnaissance survey:

- Valley, pond, lakes and other features that were not present in the topographical map.
- A number of cross drainage structures, High Flood Level (HFL), Natural Ground Level.
- Values of the gradient, the length of gradients and radius of the circular curve.
- Soil type along the routes from field identification tests and observation of the geological features.
- Sources of construction materials.

Preliminary Survey:

Sophisticated Survey Instruments are used during the preliminary survey.
Objective of the Preliminary Survey are listed below:

- To collect necessary physical information and details of topography, drainage, and soil.
- To compare different proposal in view of the requirement of good alignment.
- To estimate the quantity of earthwork.
- To finalize the best alignment.

Methods of Preliminary Survey:

- Conventional Approach
- Modern Rapid Approach

Conventional Method:

The procedure for the conventional approach are listed below:

- **Traverse:** The traverse is run from the starting point to the end point by setting out various control points. Both primary traverse and secondary traverse may need to be run.
- **Levelling work:** The levelling work is carried out along the centre line or the proposed road. The levelling work is used to estimate the volume of the earthwork. Both L-section and X-section are carried out.
- **Topographical features:** All geographical and man-made features are survey and plotted which are along the traverse and for a certain width on either side.

- **Drainage Studies and Hydrological data:** The number of cross drainage structures are estimated during the preliminary survey.
- **Soil Survey:** The soil survey is conducted in working out details of earthwork, slope, and stability of materials, subsoil and surface drainage requirements and the type of the pavement requirements.
- **Material Survey:** The location of construction materials need to be known.
- **Traffic Survey:** Survey regarding the number of lanes, roadway width, and pavement design need to be done.
- **Determination of final centre line:** After completion of all the above mention steps and calculating the amount of earthwork, the final centre line is determined.

Modern rapid approach:

The procedure of the Modern rapid approach are listed below as:

- Taking aerial photographs with required lateral and longitudinal overlaps.
- These photographs are then examined under stereoscopes and control points are selected for the establishment of the traverse.
- The spot levels and contour lines may be obtained from the stereo – pair observations.
- Photointerpretation method is used to grab information on the geological features, soil conditions, drainage requirement, etc.

Final Location and Detailed Survey:

Location: The centre line of the road which is finalized in the preliminary survey is then located in the field by establishing the centre line. Major and minor control points are then established on the ground and the central pegs are driven, checking the geometric design criteria. If necessary, the modification of the final location can be altered.

Detailed Survey:

- Temporary Bench Marks (TBM) are fixed at all under pass structures and drainage structures.
- Levels along the final centre line should be taken with great importance as these data are required for vertical alignment, earth work calculation, and drainage details.
- A detailed survey is carried out to enable drawing the soil profile up to the depth of 1.5-3m below the Ground Line and twice the height of the finished embankment in the case of the high embankment.
- The data during the detailed survey should be elaborated and completed for the preparation of the plans, designing, and estimation of the project.

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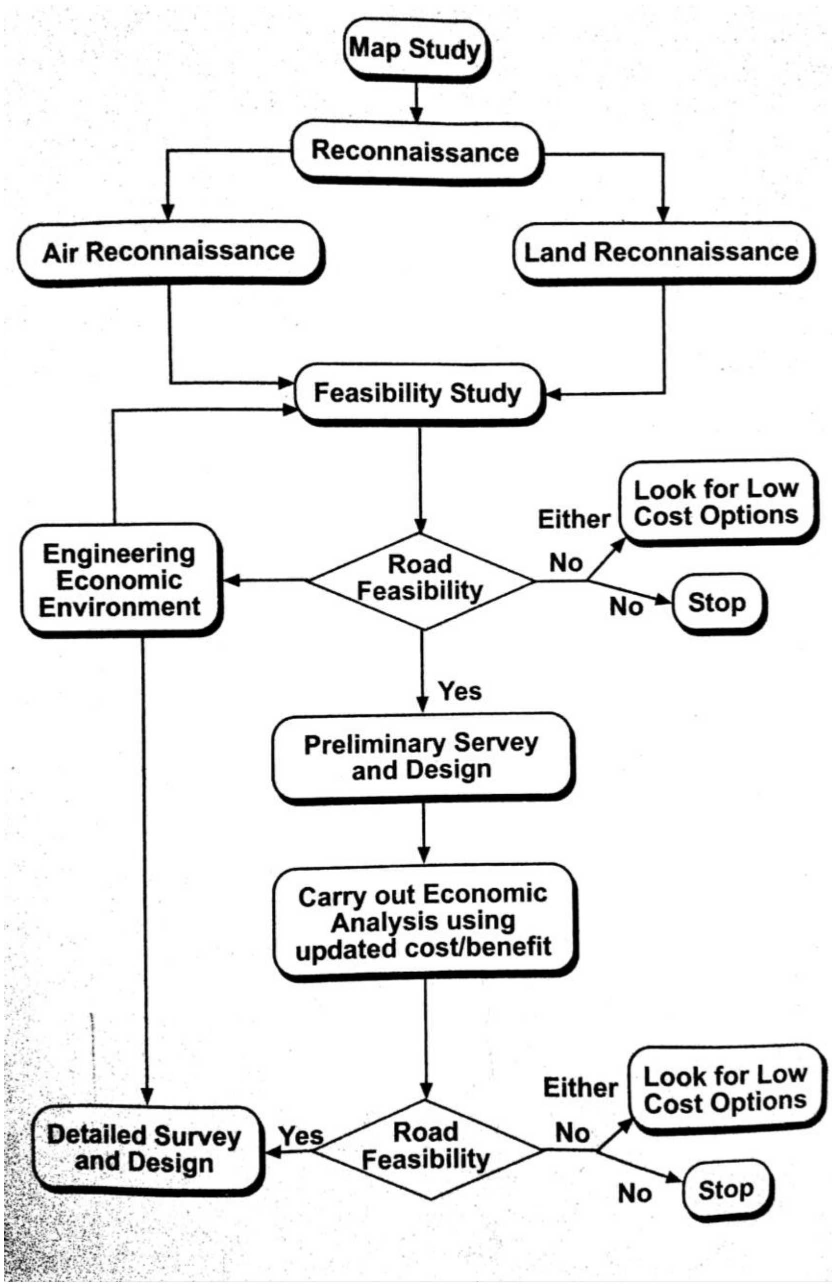

Fig: Sequence of Engineering Survey for Highway Alignment

Reference:

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Nepal Road Standard 2070

Nepal Rural Road Standard 2071

IIT Lecture Notes

4. Highway Drainage **(4 hrs)**

4.1 <u>Introduction and Importance of Highway Drainage System</u>

- Bearing capacity of soil foundation gets decreased when the moisture content in its get increased and is lowest when the same gets saturated.
- Water standing on the carriageway is danger to high speed traffic.

Highway Drainage may be defined as the process of interception and removal of water from over, under and vicinity of the road surface.

Destruction of highways by water:

- Softening the road surface constructed of soil or sand-clay or gravel or water bound macadam.
- Erosion of side slopes forming gullies, erosion of side drains, etc.
- Softening the subgrade soil and decreasing its bearing power.
- Chances of landslides and slips.

Ways of Protecting above effects:

- Interception and diversion of the surface water which would otherwise flow across the road or along it and cause erosion.
- Interception and rapid removal of seepage of subsurface water.
- Proper soil treatment
- Change of the water course

Importance of Highway Drainage:

Highway Drainage is required to mitigate the effects due to water and moisture variation that are listed below as:

- Road surface becomes soft and loses its strength.
- Road subgrade may be softened and its bearing capacity is reduced.

- Variation in moisture content in expansive soil causes variation in the volume of subgrade and thus failure of road.
- Presence of moisture at freezing temperature may damage road due to frost action.
- Erosion of side slopes, side drains and formation of gullies may result if proper drainage conditions are not maintained.
- Flexible pavement's failure by formation of waves and corrugations is due to poor drainage.
- Formation of pot holes.
- Failure of rigid pavement by mud pumping.

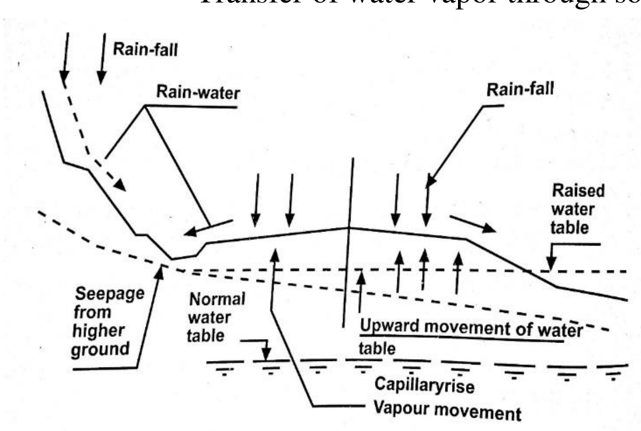
Requirements of Highway Drainage System:

- Surface water from the carriageway and shoulder should be effectively drained off without allowing it to percolate to the subgrade.
- Surface water from the adjoining land should be prevented from entering the roadway.
- The side drain should have sufficient capacity and longitudinal slope to carry away all the surface water collected.
- Seepage and other sources of underground water should be drained off by the sub-surface drainage system.
- Highest level of ground water table should be kept well below the level of subgrade, preferably by at least 1.20m.

4.2 Causes of Moisture Variation in Subgrade Soil

Moisture variation in subgrade soil can be grouped as:

1) By free water
    - Seepage of water from higher adjacent land to the road.
    - Penetration of water through the pavement.
    - Transfer of moisture from the shoulders and pavement edges.
2) By ground water
    - Rise and fall of water table.
    - Capillary rise from lower soil level.
    - Transfer of water vapor through soil.



The amount of water in subgrade soil at any point of time can be viewed as given by the equation,
$W = A + B + C - (D + E + F)$
Where, W = amount of water contained in subgrade soil at any time of the year
A = amount of water infiltrated into the subgrade soil during rainfall
B = amount of water seeping towards the subgrade from the adjacent higher ground
C = amount of water coming to the subgrade due to any or all of the following reasons:
1. Capillary rise
2. Rise of water table
3. Transfer of water vapor due to differences of temperature in upper and lower soil layers

D = loss of water from the subgrade due to flow away towards lower adjacent ground
E = loss of water due to evaporation, transpiration, etc.
F = loss of water due to percolation downward

Components of Highway Drainage System

a) Surface Drainage System
b) Subsurface Drainage System

4.3 Surface Drainage System

A part of rainwater falling on the road surface and adjoining area, is lost by evaporation and percolation. The remaining water is known as surface water. Removal and diversion of this surface water from highway and adjoining land is known as surface drainage. The water from the pavement surface is immediately removed by providing camber and cross slope to the pavement. The camber and slope depend upon the type of the pavement and the intensity of rainfall. The road surface is made impermeable to prevent infiltration of water.

Collection of Surface Water

The surface drainage may be divided into three categories as:

a) **Drainage in rural highway**
There is the provision of side drains in these areas which are generally open, unlined and trapezoidal cut to suitable cross section and longitudinal slopes. Camber is applied to the pavement to drain the surface water and has to drain across the shoulders which are provided with more cross slope. Usually, drains are provided on one or both sides in embankments while drains are provided on both sides in case of roads with cutting. Open drains are dangerous in the places where space is restricted in cutting and hence covered drains are used with layers of coarse sand gravel.

b) Drains in Urban Street

In urban roads, underground longitudinal drains are provided due to the limitation of land width, the presence of foot path, dividing island and other road facilities. This is provided where there is lesser number of natural water courses and in the presence of impervious surfaces. Water is collected in the catch pits at suitable intervals and lead through underground drainage pipes.

c) Drainage in hill roads

In hill roads, there are complex drainage problems. Water flowing down the hill has to be efficiently intercepted and disposed of downhill side by constructing suitable cross drainage works. Catch water drains at the upper hill side, sloping drains and cross slopes are provided to drain out the water whereas side drains are provided only at the hill side. If hill roads are not properly drained, rockslides and slips may occur blocking the road during monsoon season. The shape of the side drains is made in such a way that vehicles can park at that space during emergency, crossing or parking.

4.3.1 Different types of road side drain

On the basis of the shape of drain, the road side drain may be rectangular, trapezoidal, triangular or semi-circular. The type of drain may be angle drain, saucer drain or kerb and channel drain as mentioned earlier.

4.3.2 Cross Drainage Structures

Cross drainage structures are those structures which are provided whenever streams have to cross the roadway facility. The water from the side drains is also often taken across these structures in order to divert the water away from the road to a water course or a valley.

Culverts

A closed conduit placed under the embankment to carry water across the roadway is termed as culverts. In NRS 2070, culverts are the bridging structures of linear waterway span less than about 6m. It is extensively used in road drainage system. In fact, more than 75% of the cross-drainage structures are culverts. A culvert is more hydraulically efficient than minor bridge and discharge through a culvert is more than a minor bridge

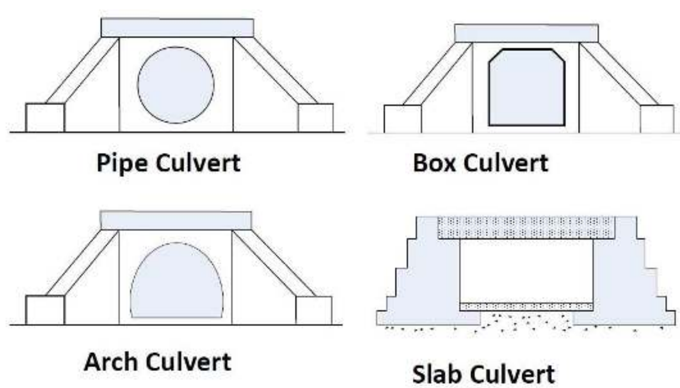
Functions of culverts

The functions of culvert are:

- Collection and transport of water across the road so as to not cause damage to the road bank or the stream bed by scouring.
- To provide sufficient waterway to prevent heading up of water above the road surface.

Types of Culvert

Pipe Culvert



- Used in non-perennial or at very small stream (Surface runoff from side drain).
- Minimum of 50cm cover of soil should be provided so that traffic load transmitted on pipe is of small intensity.
- Minimum diameter of pipe – 600mm.
- Pipes may be made of stone ware, concrete, RCC, etc. with standard sizes of 0.5m, 0.75m, 1m, 1.25m and 2m in diameter.
- For large areas, multiple pipes are used joined to each other by joints because the length of a single pipe is limited to 2.5m.

Box Culvert

- Suitable for large flow where the boulder movement may occur.
- Constructed where the nature of the soil below the foundation is not suitable for individual footing under piers and abutments.
- The size of rectangular passage should not be less than 60cm*60cm.
- The height of such culverts rarely exceeds 3m.
- These culverts have larger life spans, greater hydraulic efficiency, superior durability for worst environmental conditions and greater resistance to damage due to debris.

Slab Culvert

- They are used in stream with boulder movement and debris flow.
- These culverts are used where the water opening is less than 15 m^2 and road crosses the waterway on a relatively high embankment.
- Free board of generally 0.5m is seen in this type of culvert thus, no pressure flow occurs in this culvert.

Arch Culvert

- These culverts are suitable in high discharge areas and low debris flow areas.
- These culverts are constructed when high fillings are involved and there is heavier loading on the culvert.
- Span of each arch should be kept less than 3m.

Bridge

A bridge is a structure constructed over water course to carry traffic over it. In NRS 2070, bridges are the structures having linear waterway span more than about 6m.

On the basis of construction materials
- Steel bridges
- Concrete bridges
- Timber bridges, etc.

On the basis of structural point of view
- Cantilever bridges
- Suspension bridges
- Moving bridges, etc.

On the basis of span length
- Minor bridge (up to 30m)
- Major bridge (above 30m)
- Long bridge (above 120m)

On the basis of load carrying capacity
- Class 70 (Corresponding to class AA)
- Class 40 (Corresponding to class A)
- Class 30 (Corresponding to class B)

- Class 9
- Class 3
- Class 1

Parts of bridge

Bridge is divided into the following three parts structurally:

1. **Foundation:** Since bridges take very heavy loading upon them, the foundations should be carefully designed. If rocky strata are available for the abutments and piers at the location of bridge site it becomes very easy to construct bridge but if they are not available then well sinking may have to be done or caisson type piers or abutments may have to be constructed in the foundation site location.
2. **Substructure:** Substructure is that portion of the bridge which lies between the decking and the foundation. The various components in the substructure are wing walls, piers, abutments, etc. The choice of the type of abutment is done according to the site condition concerning the soil classification which can be made of brick masonry, stone masonry, PCC or RCC.
3. **Superstructure:** Superstructure is the portion which lies above the decking and can be made of material like: timber, steel, RCC or pre-stressed cement concrete.

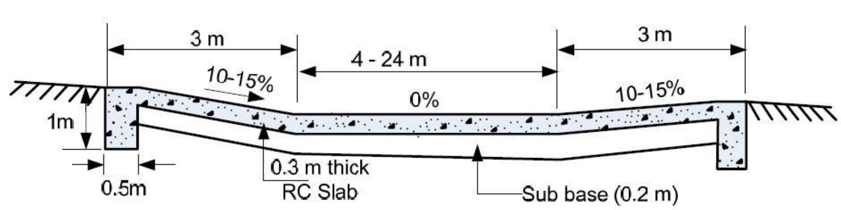
Causeway

They are constructed instead of culverts on less important roads where the maximum flow of depth does not exceed 1.5m which saves the construction cost. During the flood, the water flows over the road and traffic on both sides is stopped but as soon as the flood recedes, the traffic flow is resumed.

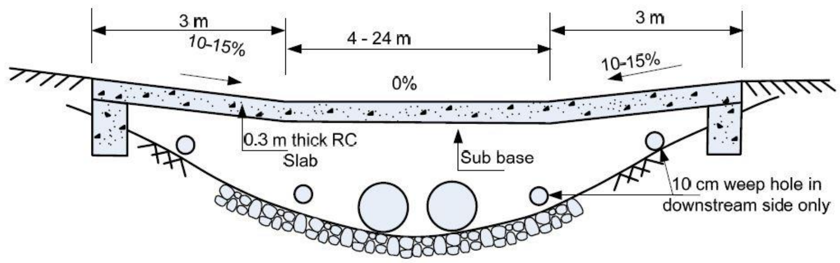
Bed slope of the causeway in estimating the span should not generally exceed (4-5) % in order to prevent the vehicles from skidding and overturning downstream. The depth of flow in most of the period of the year should not exceed 30cm.

There are two types of causeway:

1. **Low level causeways/Flush Causeway/Irish Bridge of Ford:** The causeway which is constructed at the bed level of the stream which allows flood to pass over the road surface at any time is termed as low-level causeway. It remains dry for most of the time.

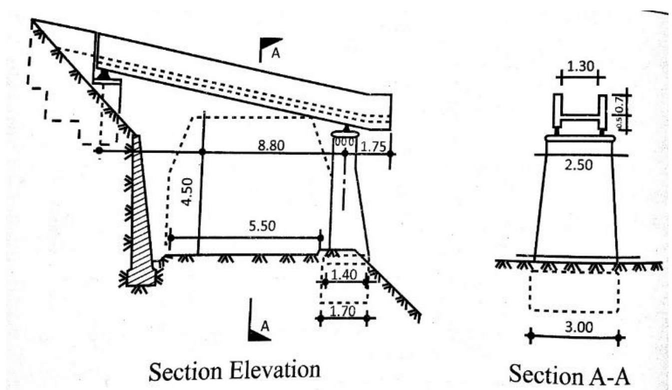


2. **High level causeways/Submersible Causeway/Vented Causeway:** The causeway which is provided with vents below to pass regular flow under the road and flood across the road surface at any time is termed as high-level causeways. It is constructed quite above the stream bed and is also termed as submersible bridge.



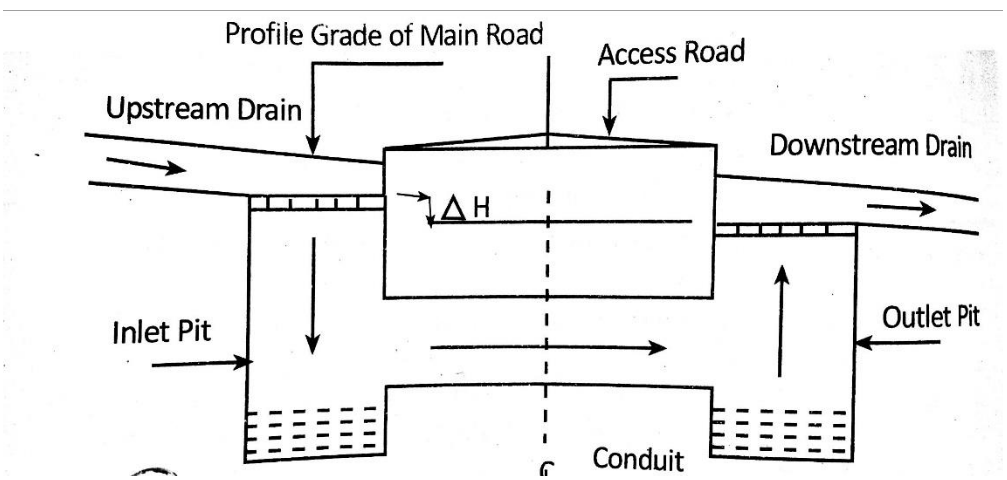
Aqueduct

Aqueduct is an open or closed conduit sufficiently above the roadway to drain water across the road with the provision of pillar supports on either side of the road. These structures can be advantageously used in hill roads where culverts are not feasible.



Inverted Siphon

The inverted siphon is a structure which lowers the invert level of the conduit to the desired level and both inlet and outlet pits are provided to receive flow from the drain and discharge water to the downstream drain respectively. . It is generally provided when the provision of culvert and aqueduct is not possible.



Sub-Surface Drainage System:

- Stability and strength of the road surface depends upon the strength of subgrade.
- With increase in moisture content the strength of the subgrade decreases.

The variation in moisture content of subgrade is caused by the free water and the ground water. Every effort is needed to reduce the moisture content to a minimum. From usual drainage system, only gravitational water can be drained by the provision of subsoil drainage.

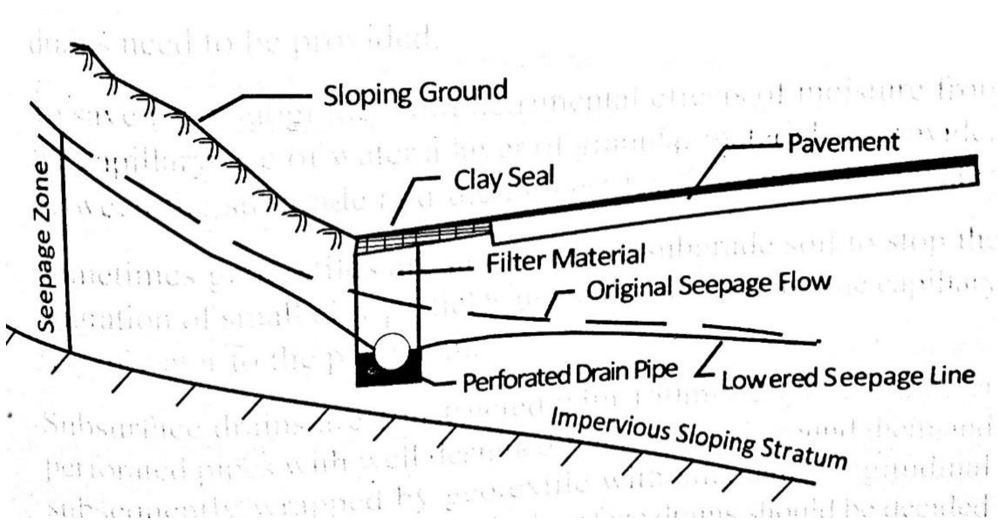
Drainage of infiltrated water

- During rainy season and snow melting season, water will find its way to the subgrade soil through the permeable surface of the adjoining land, carriageway, shoulder, side slope and cracks.
- Removal of such infiltrated water from the subgrade may be accomplished by the arrangements shown in figures below. The control of subsurface water is classified under three headings:

1. Control of seepage flow
2. Lowering of water table
3. Control of capillary rise

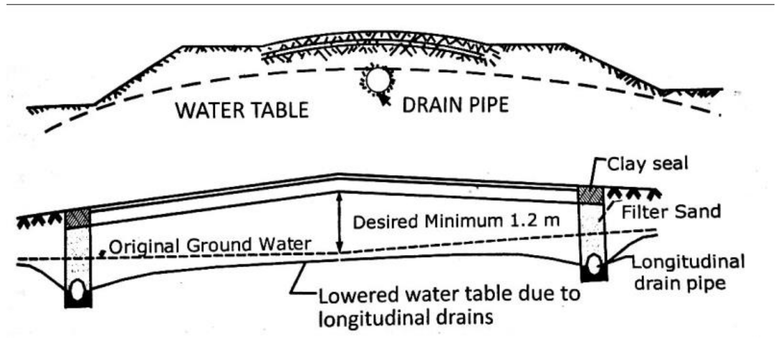
Control of seepage flow

- Seepage may occur from the higher ground in hilly topography or in road cuttings where a layer of permeable soil overlies an impermeable stratum which affects the strength characteristics of the subgrade.
- The best solution to this type of problem would be to intercept the seepage water on the uphill side of the road.
- If the seepage level reaches a depth less than 60-90 cm from the road subgrade, it should be intercepted to keep seepage line at a safe depth below the road subgrade.

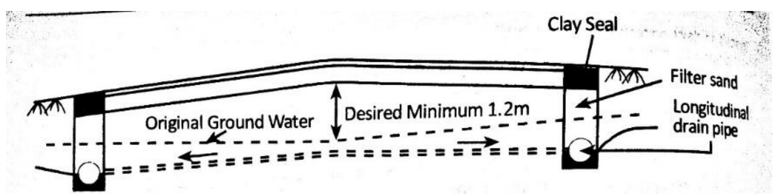


Lowering of water table

- The water table may rise and may come up to the pavement layers in low-lying areas during rainy seasons which becomes very harmful to the pavement and the subgrade especially when the subgrade is made of fine-grained soils. Therefore, it becomes necessary to lower the water table safely below the pavement.



- If the underground water table is more than 1.2m below the surface of the road, it does not require any subsurface drainage but when it is less than 1.2m the best measure would be to raise the road formation.
- The water table is lowered to the desired depth by providing sub drains on either side of the road. It may be possible to lower the water table by merely constructing longitudinal drainage trenches with drain pipes and filter sand if the soil is relatively permeable.
- But if the soil is relatively less permeable, the water table lowered at the center of the pavement or between the two longitudinal drains may not be adequate. Thus, transverse drains may have to be provided in order to effectively drain off the water and lower the water table.



- The depth to which the drains should be laid depends upon the width of the roadway, amount of water table to be lowered, type of subgrade soil and lateral distance between the trenches.
- The pipe in the drainage system should be laid such that silting and scouring do not occur.
- For maintenance of these systems, manholes and inspection chambers can be provided.

Control of capillary rise

In water logged sections, there will be possibility of rising of water to the subgrade level due to the phenomenon of capillary action which affects the strength of the subgrade. Thus, capillary cut off measures needs to be provided to free the subgrade from the excessive moisture. If the subgrade soil is of permeable type, the lowering of water table is economical but in case of retentive type of soil, drainage becomes very difficult and costly. In these cases, capillary cut offs become more economical. There are two types of capillary cut off:

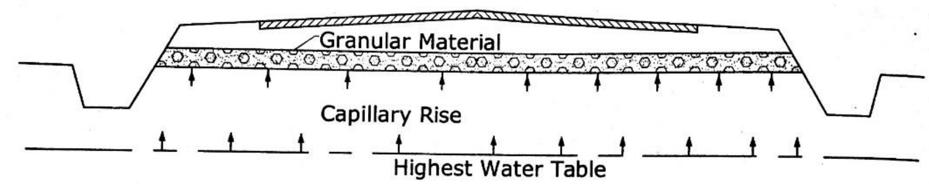
1. **Granular capillary cut off:**

    - Provision of granular material of suitable thickness between the subgrade and the highest level of subsurface water table during the construction of embankment.

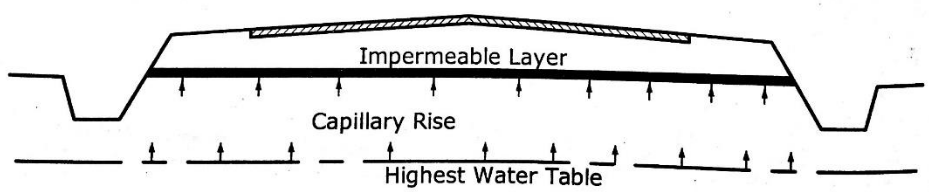
- The granular capillary cut off layer's thickness should be sufficiently higher than the anticipated capillary rise within the granular layer so that the capillary water cannot rise above the cut off the layer.
- Suitable sand blanket and gravel blanket can be used for cut off.

2. **Impermeable capillary cut off:**

- Provision of impermeable membrane such as prefabricated bituminized surfacing is used instead of granular blanket.
- Bitumen stabilized soil, heavy duty tar felt or heavy-duty polythene envelope can also be used.



Granular Capillary Cut-Off



Impermeable Capillary Cut-Off

Design of Surface Drainage System

Two Phases:

Hydrological Analysis

- The main objective of this analysis is to estimate the maximum quantity of water expected to reach the drainage system under consideration.
- Some portion of the rain water gets evaporated and infiltrated and the rest is called runoff which flows over the surface.
- The various factors which affect the run off are the rate of rainfall, type of soil, topography, vegetation, etc.
- The surface drainage to be designed should drain away all the surface water. For such analysis, initially, the details of the average intensity of the area for a selected frequency and duration equal to the time of concentration are required. Then the total and peak rainfall based on the predetermined intensity for the area under consideration is determined.

Then rational formula is used to estimate the peak run off water for the highway drainage given by:

$Q = c*i*A_d$

Where,

Q is the discharge in m^3/s,
c is the run off coefficient which is expressed as the ratio of run off to the rate of rainfall,
i the rainfall intensity in mm/sec and
A_d is the drainage area in $1000m^2$.

The value of the runoff coefficient (c) is dependent on the type of the soil surface and slope. The drainage area consists of different areas with different values of runoff coefficients c_1, c_2, c_3 with their respective areas of A_1, A_2, and A_3. Then the weighted value of the runoff coefficient for the drainage area is given by,

Therefore, $c = (A_1*c_1 + A_2*c_2 + A_3*c_3 + \ldots\ldots) / (A_1 + A_2 + A_3 + \ldots\ldots)$

The intensity of rainfall is calculated from the rainfall data obtained initially which are the frequency and the expected duration of the rainfall. From the data, the inlet time and the time for the flow of water from the farthest point to the drainage are calculated which gives the time of concentration and the intensity of rainfall.

The drainage area is determined to study contour map and topographic maps. The estimated maximum quantity of water calculated for the drainage element now helps in the design of the drainage structures.

Hydraulic Analysis

The side drains and the culverts are now designed on the principles of flow through open channels once the maximum discharge has been calculated.

Then, $Q = A * v$

Where, Q is the quantity of the surface water in m^3/s to be removed from side drains, v is the velocity of the water in the channel and A is the required area of the drain.

The velocity is calculated using Manning's equation assuming uniform and steady flow through a uniform cross section and slope,

Or, $v = (1/n) * R^{2/3} * s^{1/2}$

Where,

v is the average velocity in m/s,
n is the Manning's coefficient which depends upon the type of soil,
R is the hydraulic radius in meters and
s is the longitudinal slope of the channel.

The design procedure is as follows:

1. The hydraulic radius is calculated for a permissible non-scouring velocity from Manning's equation,

$R = [(n*v) / s^{1/2}]^{3/2}$

2. The minimum cross-sectional area is calculated from the permissible non-scouring velocity and the maximum discharge,

$A = Q / v$

3. The wetted perimeter is calculated,

$P = A / R$

4. Determine the dimensions of the drain i.e. the breadth and width by relating the area and perimeter.
5. The depth of flow found should be greater than the critical depth $[v^2 /g]$
6. If depth is less than the critical depth, erosion may occur at the downstream end and therefore process should be revised or special measures should be provided at the downstream.

Design of subsurface drain

Design of subsurface drain consists of the following steps:

1. **Depth of the drainage trench:** The depth of the trench at which the subsurface flow has to be intercepted is determined on the basis of impervious stratum level, soil type and the requirement at which the subsurface flow has to be maintained.
2. **Selection of the backfill filter material for the trench:** The back-fill's purpose is to improve the interception ability of the drain and to provide effective water collecting space adjacent to the pipe. Such materials should be coarse enough to allow water to have easy access to the pipe but also should be fine enough to act as a filter material to prevent base soil from intruding into the pipe.
3. **Size and number of perforations in the drain pipe:** The size and the number of holes per meter length of the pipe is determined in such a way that:

- The pipe should be able to intercept all the water entering the drain without causing a high head in the filter material as this will reduce both the depth to which the water table can be lowered and its rate of lowering
- The holes should be sufficiently small enough to prevent the filter material from being washed into the pipe and plug the holes.

- The following criteria have been recommended with respect to the size of the pipe perforations. Maximum size of circular holes = d_{85} (filter)

  Maximum width of slotted holes = $0.83*D_{85}$ (filter)

4. **Diameter of the drainage pipe:** The diameter of the pipe for a given length should be selected in such a way that the pipe will not run full near its outlet and flood the surrounding filter material. It must also be big enough so that all the intercepted water can be discharged through the pipe.

   Currently no authoritative single recommendation is available with regard to the diameter and length of the pipe. But in practice 150mm diameter pipe are commonly used. The design of these factors is the function of the amount of water to be drained off, soil type, filter, underground flow, etc. and the above recommendations may not always be followed.

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Hill Roads

5.1 Introduction

A hill road may be defined as the one which passes through a terrain with a cross slope of 25% or more. There may be sections along hill roads with the cross slope less than 25%, especially when the road follows a river route. Even then these sections are also referred to as hill roads. Hence, to establish a hill road overall terrain must be taken into account.

The hilly regions generally have extremes of climatic conditions, difficult and hazardous terrains, topography and vast high altitude areas. The region is sparsely populated and basic infrastructural facilities available in plain terrain are absent. Hence, a strong stable and feasible road must be present in hilly areas for overall development of other sectors as well.

Design and Construction Problems

Design and Construction of roads in hills and mountain are more complex than in plain terrain. It is due to several factors associated in the region. They are:

- A hilly or mountainous area is characterized by highly broken relief with vastly differing elevations and steep slopes, deep gorges etc. which may unnecessarily increase road length.
- The geological condition varies from place to place.
- Hill slopes stable before construction may not be as stable due to increased human activities.
- There may be variation in hydro-geological conditions which may easily be overlooked during design and construction
- Due to highly broken relief construction of special structures should be done at different places. This increases the cost of the construction.
- Variation in the climatic condition such as the change in temperature due to altitude difference, pressure variation, precipitation increases at greater height etc.
- High-speed runoff occurs due to the presence of high cross slopes.
- Filling may overload the weak soil underneath which may trigger new slides.
- The need of design of hairpin bends to attain heights.

5.2 Special Consideration in Hill Road Design

Alignment of Hill Roads

Selecting an alignment in the hilly region is a complex task. The designer should attempt to choose a short, easy, economical and safe comforting route.

General considerations

When designing hill roads the route is located along valleys, hill sides and if required over mountain passes. Due to complex topography, the length of the route is automatically increased. Due to harsh geological conditions, special structures also have to be provided.

Apart from the highly broken relief which has a fixed role in determining the alignment and location of special structures, climatic and geological conditions are also important. In locating the alignment special consideration should be made in respect to the variations in:

1. Temperature
2. Rainfall
3. Atmospheric pressure and winds
4. Geological conditions

Temperature

- Air temperature is in the hills is lower than in the valley. The temperature drop being approximately 0.5° per 100 m of rising.
- On slopes facing south and southwest snow disappears rapidly and rain water evaporates quickly while on slopes facing north and northeast rain water or snow may remain for the longer time.
- Unequal warming of slopes, sharp temperature variations and erosion by water are the causes of slope facing south and southwest.

Rainfall

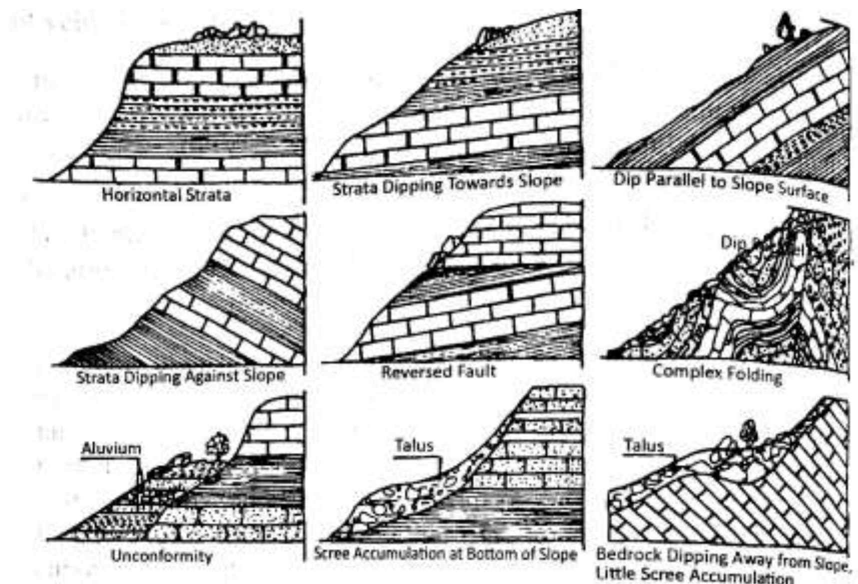
- Rainfall increases with increase in sea level.
- The maximum rainfall is in the zone of intensive cloud formation at 1500-2500 m above sea level. Generally, the increase of rainfall for every 100 m of elevation averages 40 to 60 mm.
- In summer very heavy storms may occur in the hills and about 15 to 25% of the annual may occur in a single rainfall. The effects of these types of rainfall are serious and should be considered well.

Atmospheric pressure and winds

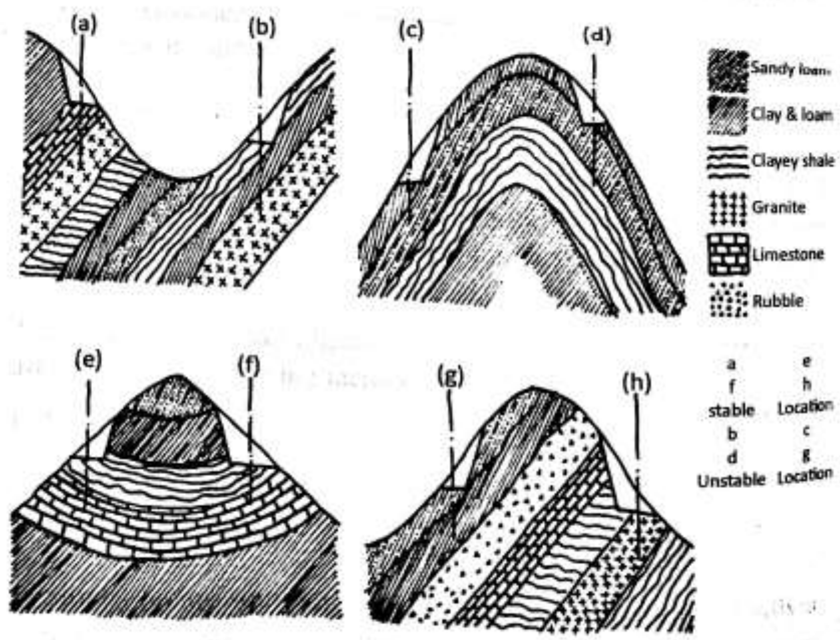
- It decreases with increase in elevation.
- At high altitudes, the wind velocities may reach up to 25-30 m/s and depth of frost penetration is also 1.5 to 2 m.
- Intensive weathering of rocks because of sharp temperature variations which cause high winds.

Geological conditions

- The inclination of folds may vary from horizontal to vertical stratification of rock. These folds often have faults. Limestone or sandstone folds may be interleaved with layers of clay which when wetted may cause fracturing along their surface. This may result in shear or slip fold.
- The degree of stability of hill slopes depends on types of rock, degree of strata inclination or dip, occurrence of clay seams, the hardness of the rocks and presence of ground water.



Various Structures of Slopes



When locating the route an engineer must study the details of geological conditions of that area and follow stable hill slopes where no ground water, landslides, and unstable folds occur.

Route location in Hills

Hill roads may follow different path according to the feasibility of the road. However, a hill road alignment varies for the sections along the valley bottom and along the mountain pass. The first is called **river route** and the second is called **ridge route**.

River route

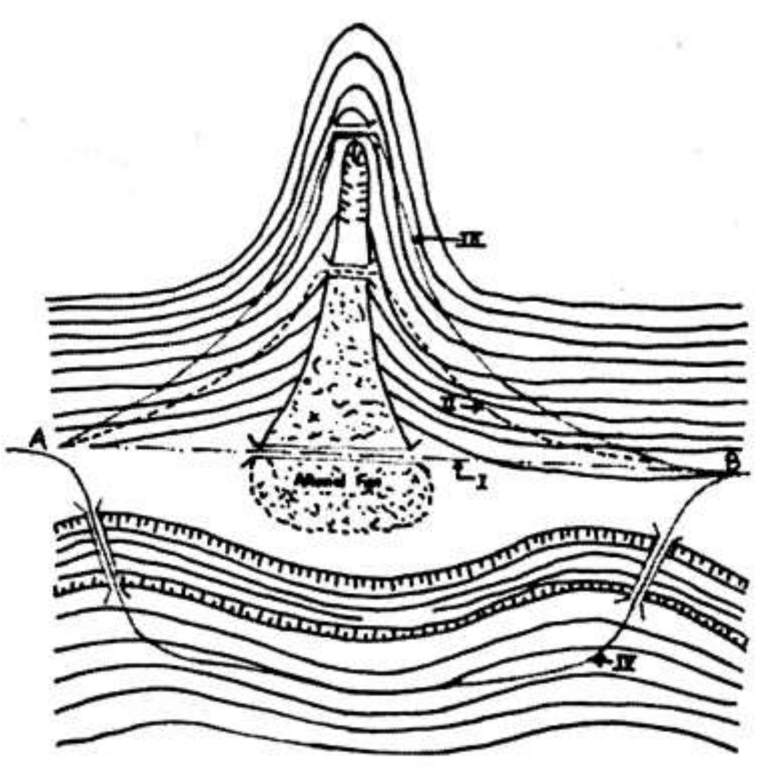
The location of a route along a river valley is the most frequent case of hill alignment as there is a great advantage of running a road at a gentle gradient. Also, there is a benefit of low construction cost and operation cost.

However, a river valley may run through numerous horizontal curves. Requirements for the construction of large bridges over tributaries also may occur. It may also be necessary to construct special retaining structures and protection walls on hill side for safe guarding the road against avalanches.

Some important considerations

- Road bed should be located sufficiently above and away from the maximum water level.
- When the road bed is near to the waste water course embankment slope should be well protected and stabilized.
- More care should be given to geological and hydrological structures.
- Best alternatives should be selected for crossing water sources.
-

For example, as shown in figure a road is to be connected from A to B.

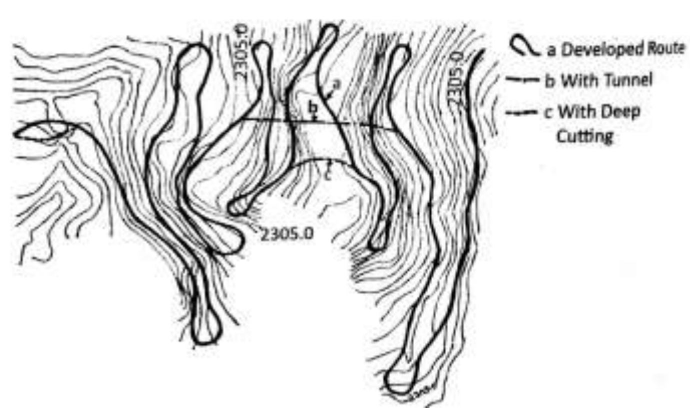


The first alternative runs through alluvial making a bridge. However, it may not be feasible unless there are strong foundations which may increase construction cost greatly.

The second alternative is located above the alluvial fan through which the bridge length is greatly reduced

Similarly, other options like route III or IV may also be chosen depending upon the economic comparison.

Ridge route



- It is characterized by the very steep gradient.
- A large number of sharp curves occurs on the road with hair pin bends.
- Extensive earthwork is required.
- The requirement for the construction of special structures.
- The necessity of long length away from the air route.

Gradient

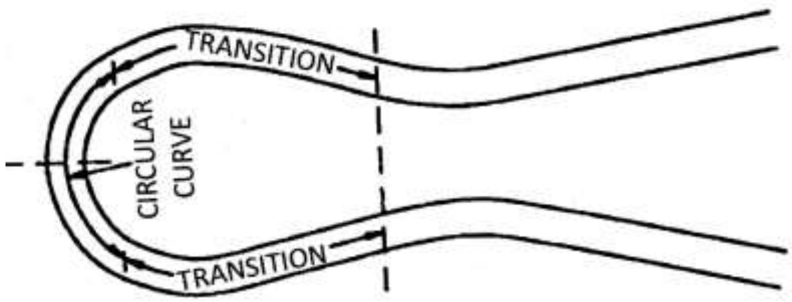
In hill roads, a heavy amount of earthwork is required. So to reduce the earthwork for reducing construction cost the gradients selected are close to maximum. Although steep gradients help in reducing earthwork and length of road, it also causes increased fuel consumption and reduction in operating speed as the vehicles will be on low gears which will use more energy. So both these factors must be taken into account and a suitable solution should be chosen.

The cumulative rise or fall in elevation should not exceed 100 m in mountainous terrain and 120 m in steep terrains. Vertical curves are designed as the square parabola. The curves should be provided at all grade change exceeding those indicated in the table below:

Design speed	Maximum grade change not requiring a vertical curve	Minimum length of vertical curve
Up to 35kmph	1.5%	15m
40kmph	1.2%	20m
50kmph	1.0%	30m

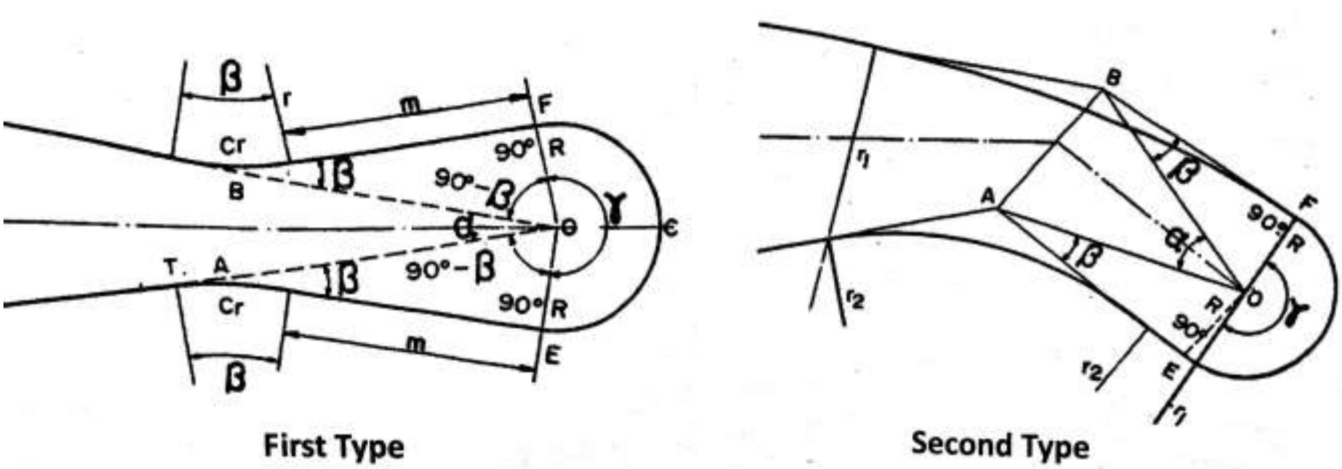
Design of Hair Pin bends

When inscribing a curve inside a turning angle the length of the route will be substantially reduced, which result in steep gradients. In such circumstances, it is preferred to round off the route by circumscribing the curve rather than inscribing the curve around the turning point. Such compound curves are called hairpin bends or reverse loops. A hairpin bend is located on the hill section having the minimum cross slope and maximum stability. It must be safe against landslide and ground water seepage.



According to NRS-2070 the design criteria is as follows:

Minimum design speed	20 kmph
Minimum radius of curve	15 m
Minimum length of transition curve	15 m
Minimum longitudinal gradient	4%
Maximum superelevation	10%



The figure shows two different kinds of symmetrical hair pin bends consisting of main curve 'C' reverse curves 'Cr; and tangents 'm'. The acute angle of the bend is α. The main curve with radius R has a total length C and subtends and angle γ at the center. Points A and B are located at the apices of reverse curves. Between the ends of reverse curves and main curve of the bend, tangents must be introduced for the transitions of super-elevation and extra-width of the curve.

For the design and layout of hairpin bends, elements such as radii of the main and reverse curves (R and r), the length of tangents m are selected. The design of hairpin bends then basically consists of establishing the value of turning angle β at point A and B which satisfies the preselected parameters of the bend.

Deriving simple expressions (with respect to the first type)

Tangent length of reverse curve

T = r Tan β/2

where,

T - Length of the tangent

r - Radius of the Reverse Curve

β - Deflection Angle

The distance from the apex of the reverse curve angle to the commencement of the main curve is given by: (See side image)

Calculating these parameters hair pin bend can now be plotted on a contour map or set out on the ground. The bends described so far which have reverse curve situated on their convexities in opposite direction are called hair pin bends of the first type.

In the bends of the second type, which may also be either symmetrical or asymmetrical, the convexities of curve face on the same side. These bends are introduced at places with contours representing shallow drainage basin or flat hill nose.

$$AE = BF = T + m$$

From ΔAOE or ΔBOF if will be found that

$$\tan\beta = \frac{0E}{AE} = \frac{R}{T+m} = \frac{R}{r\tan\frac{\beta}{2} + m}$$

Where,
R is the radius of main curve.

From trigonometry, it is also be known that:

$$\tan\beta = \frac{2\tan\frac{\beta}{2}}{1-\tan^2\frac{\beta}{2}}$$

Substituting this expression for tan β in proceeding expression, solution for $\tan\frac{\beta}{2}$ becomes:

$$\tan\frac{\beta}{2} = \frac{-m+\sqrt{m^2+R(2r+R)}}{R+2r}$$

Hence, the angle β to correspond to 'R', 'r' and 'm' can be easily determined.

The distance from the apex of the reverse curve to the centre of the main curve is determined by:

$$AO = 0B = \frac{T+m}{\cos\beta} = \frac{R}{\sin\beta}$$

The centre angle γ corresponding to the main curve of the bend is:

$$\gamma = 360^\circ - 2(90^\circ - \beta) - \alpha = 180^\circ + 2\beta - \alpha$$

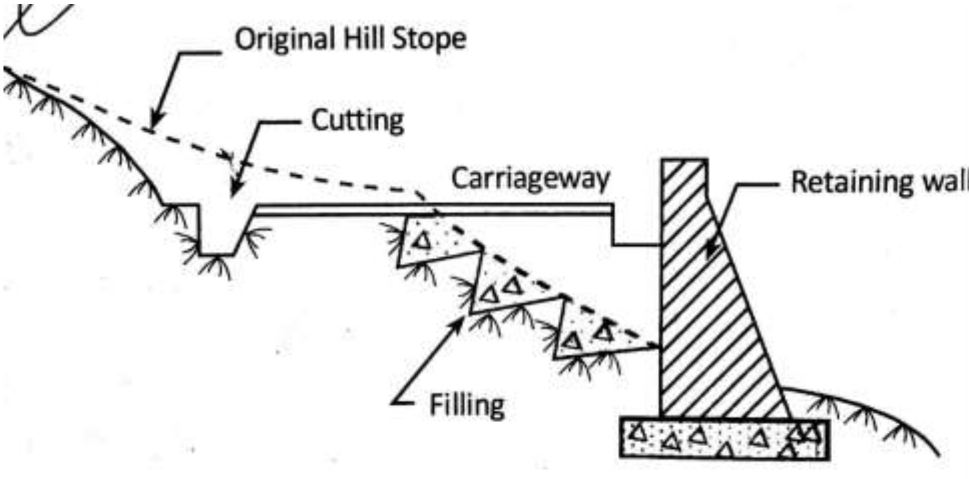
And the length of the main curve is $C = \frac{\Pi R\gamma}{180}$

Hence the total length of the bend is

$$S = 2(Cr + m) + C$$

Where Cr is the length of the reverse curve.

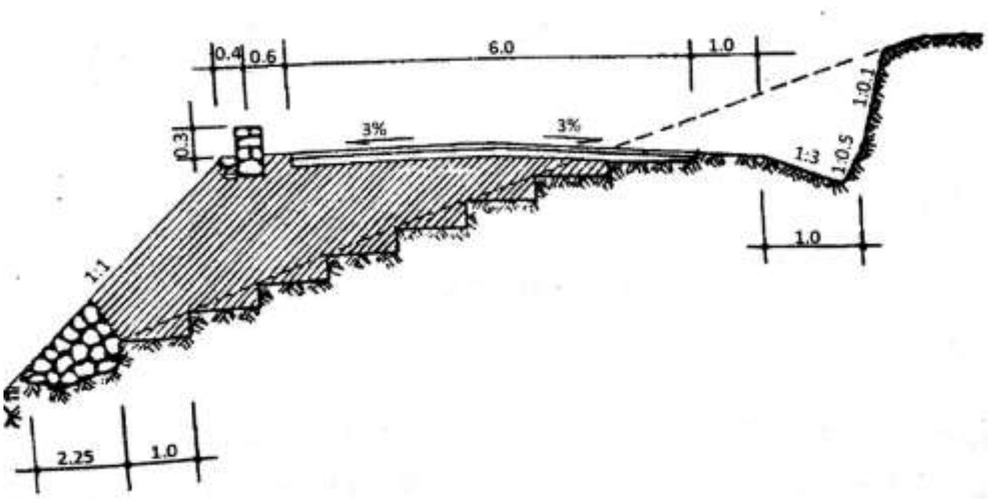
Typical Cross Sections of Hill Road



The cross section of a road in a hilly terrain is determined by the original ground slope of the site, the slope of the road formation, width of roadway, side drain size, and shape and so on. Various types of road cross-section are:

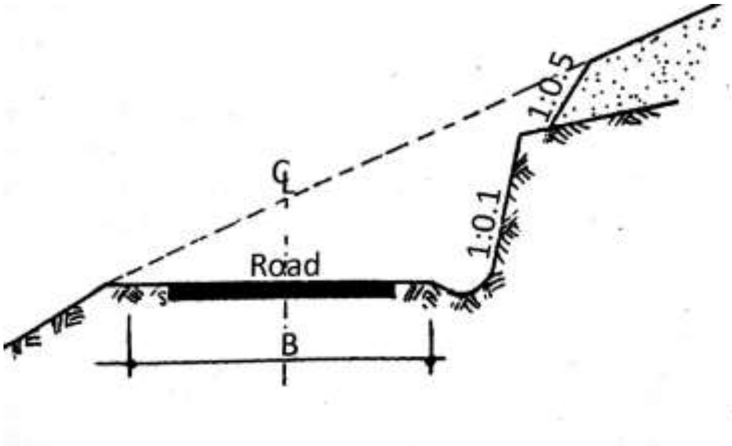
1. Cut and fill
2. Bench type
3. Box cutting
4. Embankment with retaining walls
5. Semi bridge
6. Semi tunnel
7. Platforms

Cut and fill



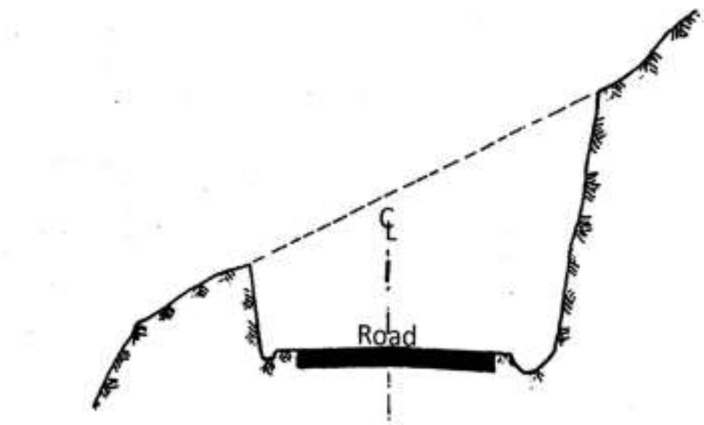
When roadbed slope has a gradient 2% or more a cut and fills road bed is cheaper and environmentally friendly as well. The fill mass is generally balanced by the cut mass. For adequate stability, benches are made on the surface of the hill side with a height of 0.5 m and length varying from 1.5 to 3.0 m depending upon the slope.

Bench type



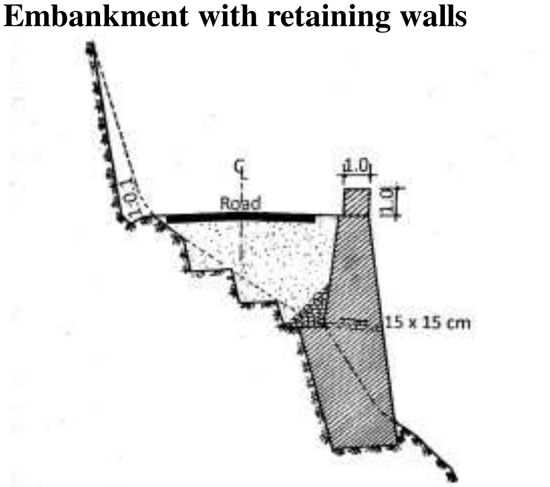
A cross section of the bench type although entails some increase in earthwork but ensures the complete stability of the road bed, if hill side is itself stable.

Box cutting



When the location of road bed is unstable or unsuitable along the hillside due to one or other reasons, the road bed is designed as trench type of cross section. It increases earthwork to a large extent. It is introduced to meet the geometric design standards for a given category road.

Embankment with retaining walls



On steep slopes of about 30-35°, the earthwork involved in constructing the embankment increases substantially. The retaining wall is sometimes provided to reduce earthwork's cost and to increase stability. Also, the retaining wall is provided when embankment soil on steep grounds itself need support. They may also be constructed on a less steep ground slope to increase the stability of road bed.

Semi Bridge

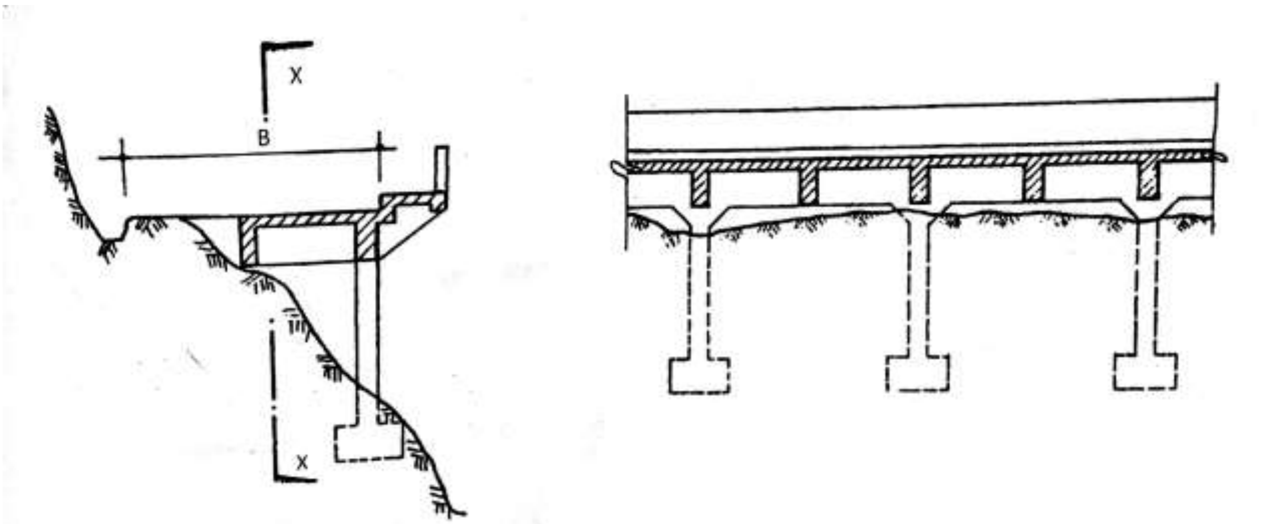


Fig: Cross Section and L-Section (X-X) of a Semi-Bridge.

If the road is located on a hill slope the retaining wall needs to be at a substantial height. In such cases, to reduce quantities of work, road bed with a semi-bridge type of structure may be constructed.

Semi tunnel

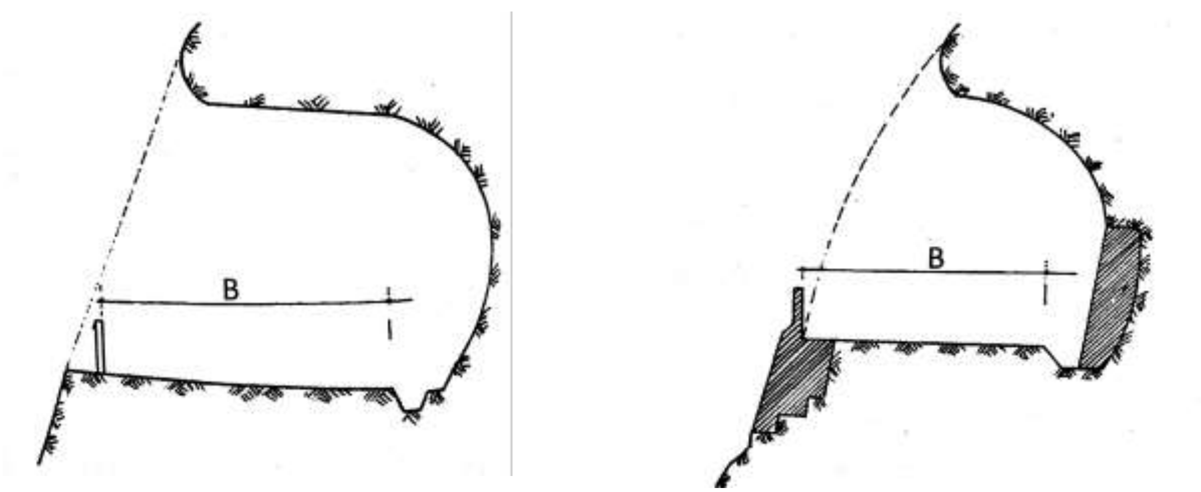
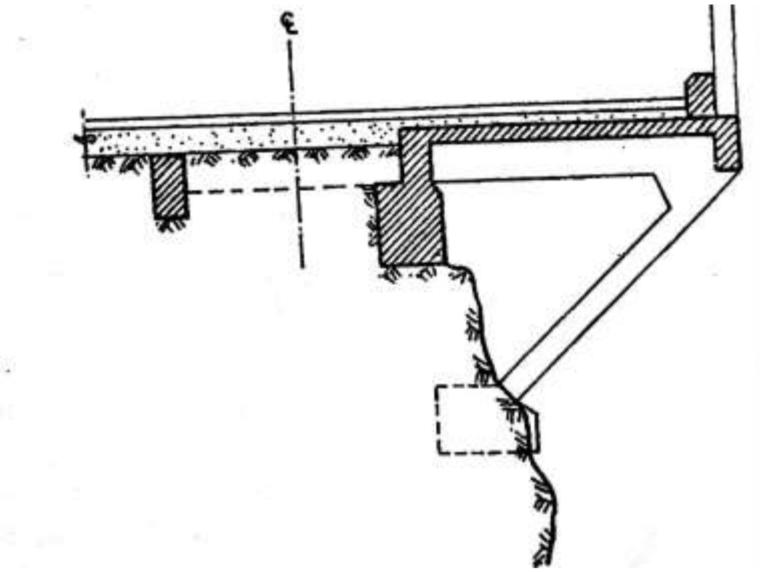


Fig: With Accommodating Road-Way Only and With Retaining and Breast Walls

When inscribing is to be cut into steep hills in stable rock faces, the rock may be permitted to overhang the road to reduce rock works. Such a cross section is called a semi-tunnel.

Platform



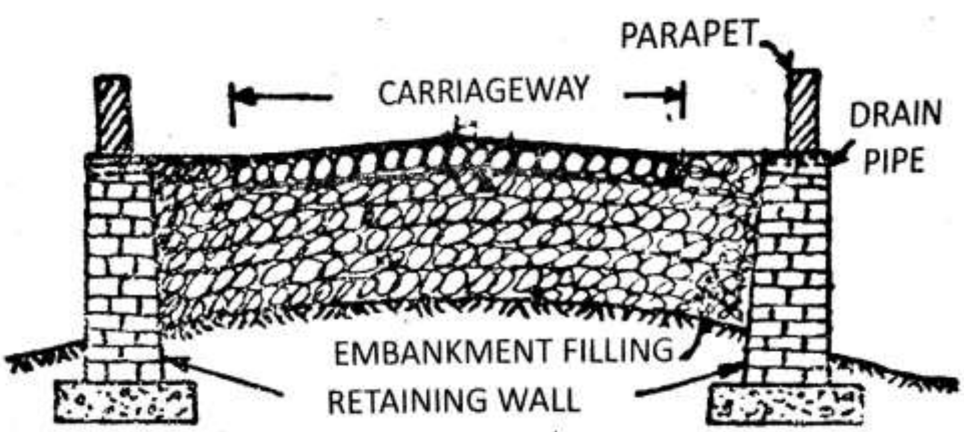


Fig: Fully In Embankment

On the precipitous slopes, where shifting of the route into the hillside will lead to enormous rock works which eventually increases the cost and where semi-tunnel cannot be constructed, platforms are usually cantilevered out of the rock on which road way is partially located.

5.3 Special Structures in Hill Roads

When constructing hill roads a lot of special structures are required owing to harsh geological and hydrological conditions as well as highly broken relief.

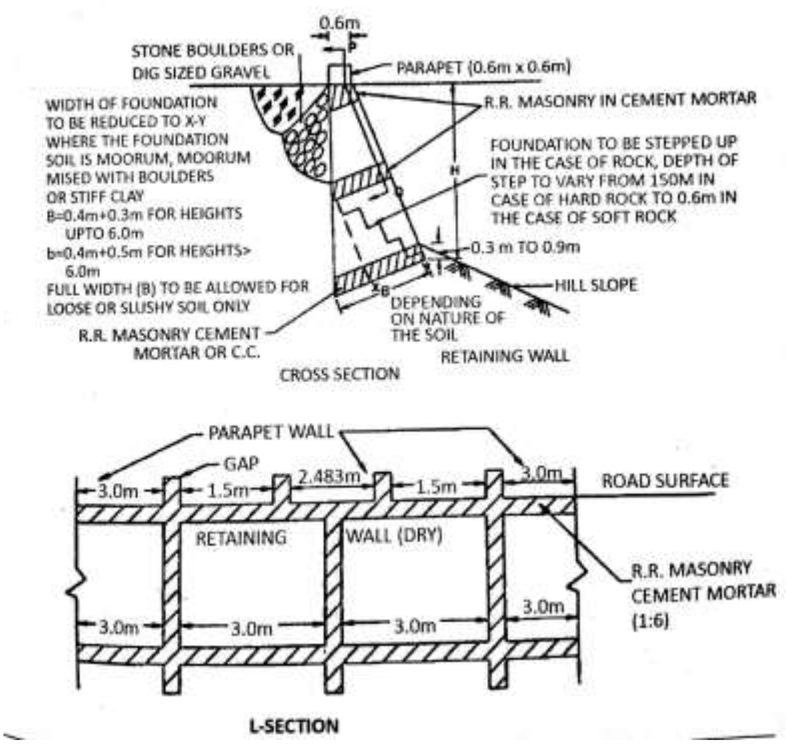
The following types of structures are mostly used in the hill roads for strength durability and stability:

1. Retaining structures
2. Drainage structures
3. Slope protection structures

Retaining structures

A retaining structure is usually a wall constructed for supporting vertical or nearly vertical earth bank. Retaining walls are constructed on the valley side on the cut hill side to prevent the the slide towards the roadway. Situations where construction of retaining walls is required:

- Places where the valley side surface gets saturated in the monsoons and is likely to result in slip taking a part of the the road with it.
- Places where undercutting by a stream or other water course causes damage to the valley side and the road.
- In valley point where water flows over the road
- To achieve roadway width, where cutting into the the hill is not economical or has to be restricted due to other reasons.



Types of retaining walls

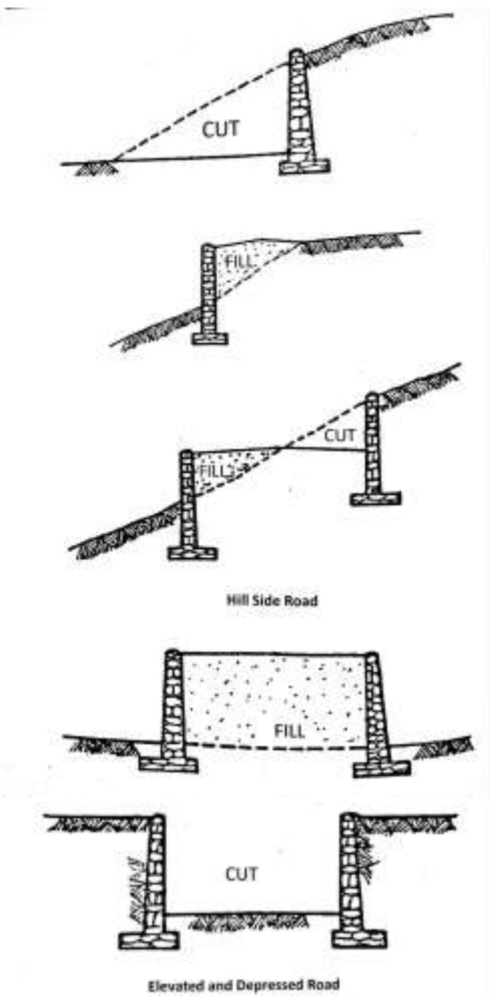
Retaining walls can be classified according to:

1. **Materials used:** based on materials used in constructing retaining walls in hill road may be made of dry stone masonry, stone filled gabion wire crates, stone masonry with cement sand mortar, plain or reinforced concrete wall, steel or timber.
2. **Structural location:** based on where the walls are constructed, retaining walls may be:
3. Gravity wall
4. Semi-gravity wall

- Cantilever wall

1. Counterfort wall
2. Buttressed wall
3. Crib wall

- Reinforced soil wall



Design of retaining walls

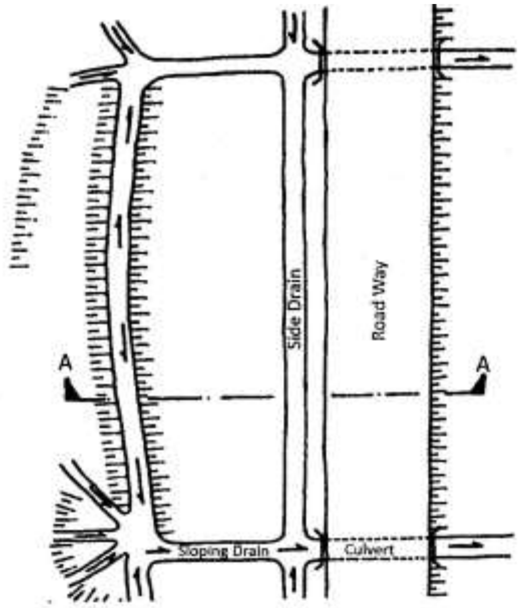
1. Assemble the general information- topographical and physical surveys.
2. Analyze the subsoil condition.
3. Establish surcharge load- highway, building, and other loads
4. Select the type and tentative proportion of the wall.
5. Compute the earth pressure and surcharge pressure.
6. Analyze the structural stability.
7. Analyze foundation stability.
8. Design structural elements.
9. Select drainage in backfill.
10. Predict settlement and movement of the wall.

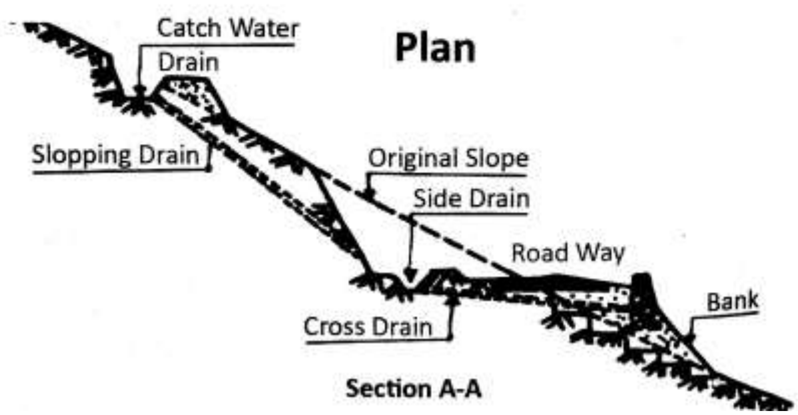
Drainage Structures

The main problems that hill roads face are the harmful effect of water. Water may come from different sources to the parts of the road. This water must be drained using any means necessary. Drainage of hill roads can be studied under following sub-topics:

1. **Drainage of water from hill slope**

Surface water flowing from the hill towards the roadway is one of the main problems in the drainage of hill roads. Since a large amount of water flows along with debris from the hill slopes during heavy storms, a catch drain is generally provided to catch the water in the middle of the slope. Water intercepted in catch water drains are then diverted by sloping drains and carried to the nearest watercourse or to culvert to cross the roadway. The figure below shows a layout for drainage from hill slopes.

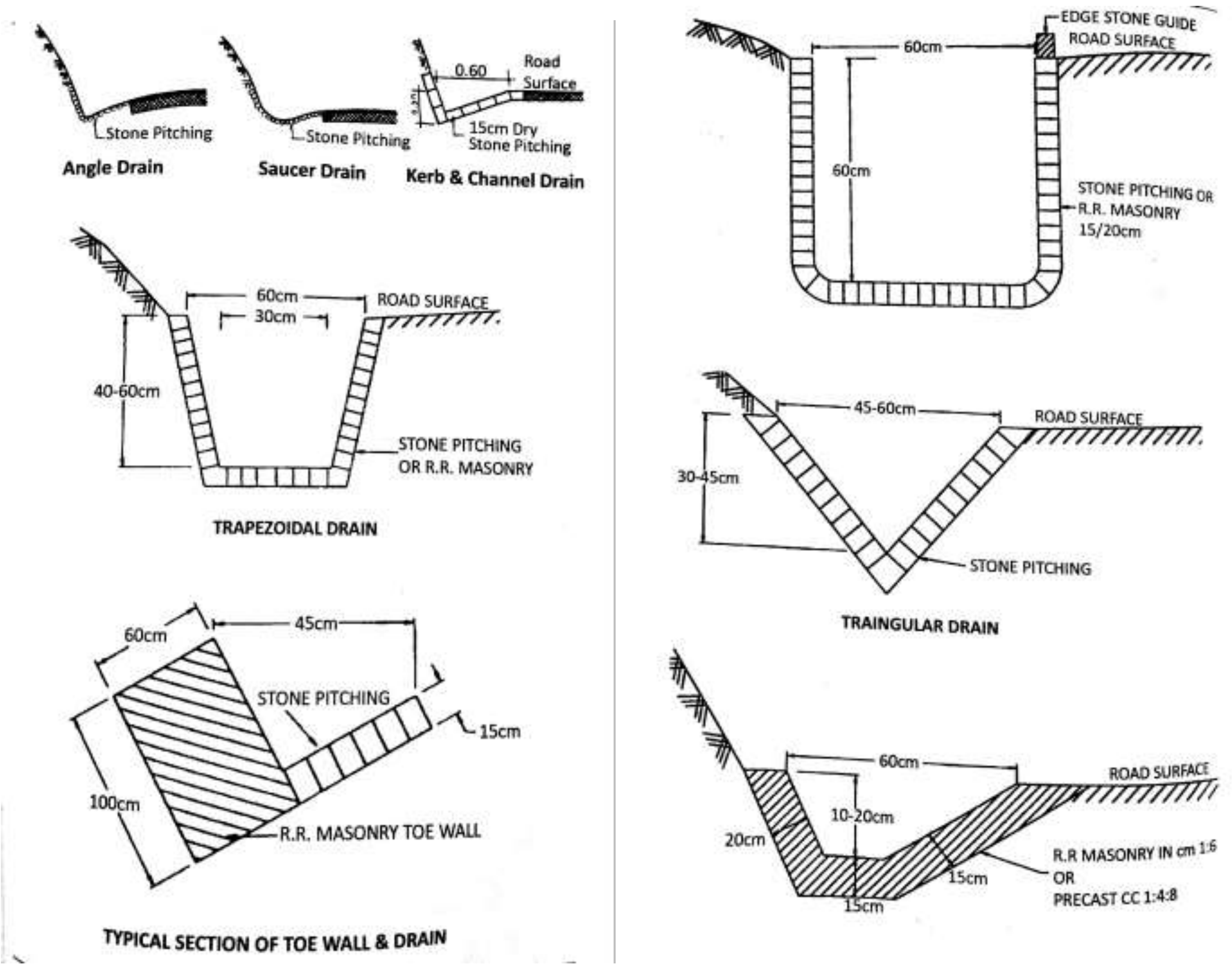


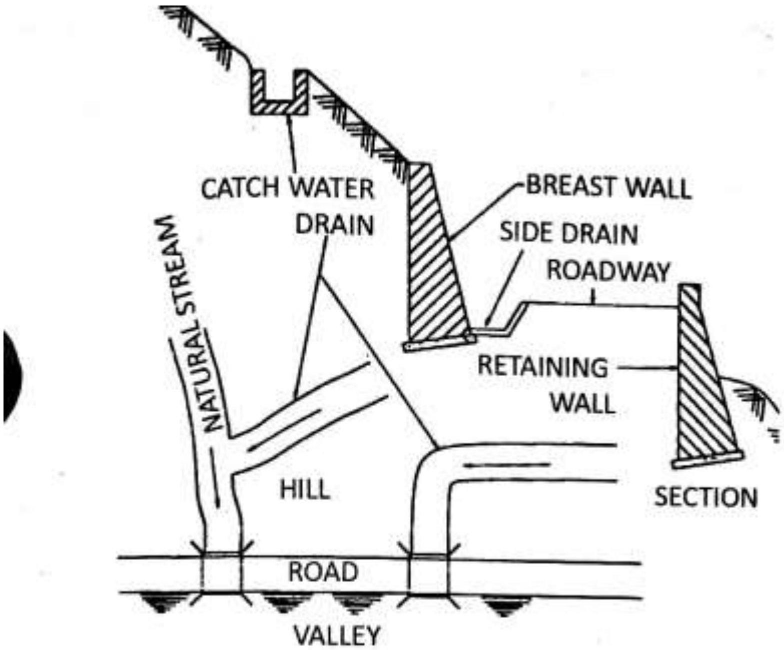


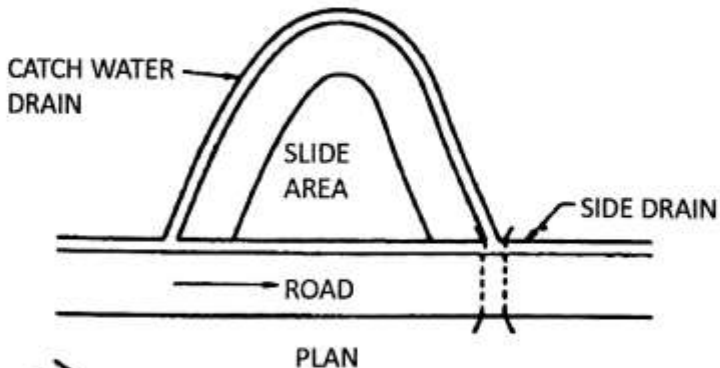
Section A-A

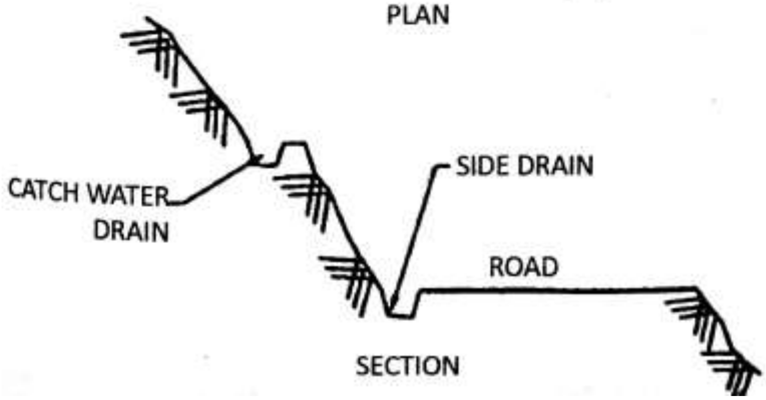
2. **Roadside Surface Drainage**

Side drains are provided all along the hill side of the road. Due to the limitation in the formation width side drains are usually constructed to such a shape that at emergency the vehicles could utilize this space for crossing. The shapes may be angular, saucer or kerb and channel drains.



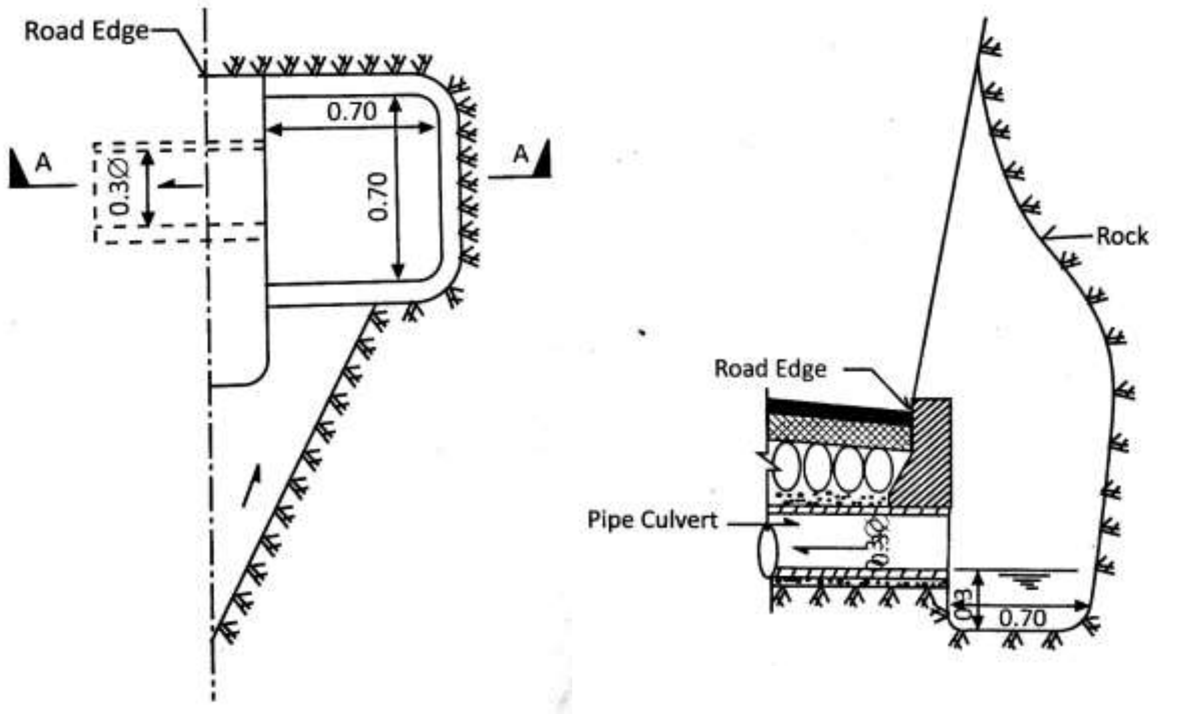

CATCH WATER DRAIN
BREAST WALL
SIDE DRAIN
ROADWAY
NATURAL STREAM
RETAINING WALL
HILL
SECTION
ROAD
VALLEY


CATCH WATER DRAIN
SLIDE AREA
SIDE DRAIN
ROAD
PLAN


CATCH WATER DRAIN
SIDE DRAIN
ROAD
SECTION

3. **Cross drainage**

A cross drainage is always required on a hill road. The drainage must be taken under the road as far as possible. At the heads of the small cross drains, catch pits must be provided to collect debris and to prevent scouring.



4. **Subsurface drainage**

Seepage flow is one of the major problems in hill road. Ground water may seep across hillside above or below the road level depending upon several factors such as nature and depth of hard stratum, its inclination, the quantity of ground water etc. sub-surface drainage control may be done by methods in the previous chapter.

Slope Protection Structures

In hill roads, landslides are very common due to steep slopes. The basic cause of landslide is the development of shear stresses more than the shear strength of the soil. Fresh unturfed embankment and cut slopes are the least stable part of the road bed since the soil on the surface of the slopes is subjected to the direct action of sun, rain, and wind.

Causes of landslides

- Increase in moisture content of the soil in hill slopes which increases the pore water pressure.
- Alternate swelling and contracting of the soil mass.
- Seepage pressure of percolating groundwater.
- Steeper slopes.
- Human activities like blasting and using heavy vehicles at unstable zones.

Preventive measures

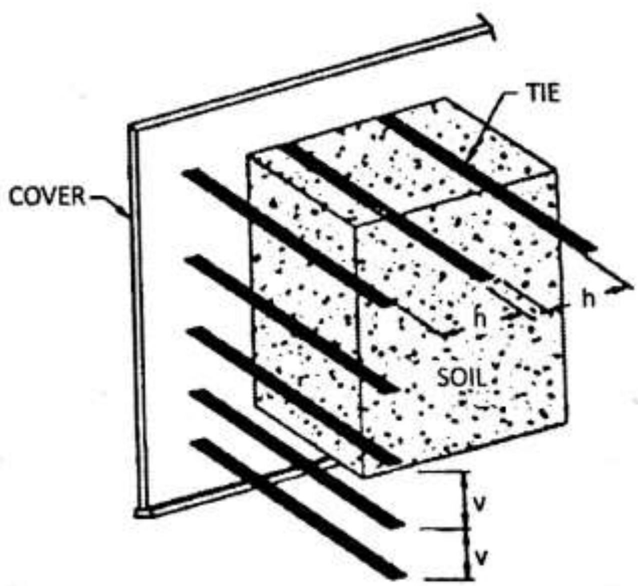
- The highway may be realigned at areas more prone to landslides.
- Construction of retaining walls must be done at places where required
- Adopting easy slopes during design and construction of the road.
- Treatment of slopes to increase stability conditions.

Reinforced retaining walls

This is a type of retaining wall of composite construction material in which strength of fill is enhanced through the addition of inextensible tensile reinforcement in the form of strips, sheets, grids, or geotextiles.

It is suitable for hill roads because:

- The fill material is readily available at cheaper cost.
- The land required for embankment is less.
- Cost effective, easy to construct and environmentally friendly.
- It causes less alteration in natural slope.



River training structures

River training refers to the structural measures which are taken to improve a river and its banks.

River training is an important component in the prevention and mitigation of flash floods and general flood control, as well as in other activities such as ensuring the safe passage of a flood under a bridge. Hill roads along the river may also be in danger due to different problems created by it.

Problems created by river

- Frequent changes in river course.
- Avulsion of one river into another.
- Development of natural cut-off.
- Landslides in catchment -rise in silt load.
- Aggradation of river bed -high flood levels –Flooding
- River instability -change in bed slopes (seismic activity).
- Degradation of river bed downstream of a dam or a barrage.
- Effects of flood embankment on the regime of rivers.
- Effects of extraction of sand and boulders.
- Effects of heavy urbanization along the river banks.

River training structures

River training structures can be classified into two main categories:

- Transversal protection structures

Installed perpendicular to the water course:

Check dams, Spurs, Sills, Screen, bands, Porcupines, Bank protection as a bar.

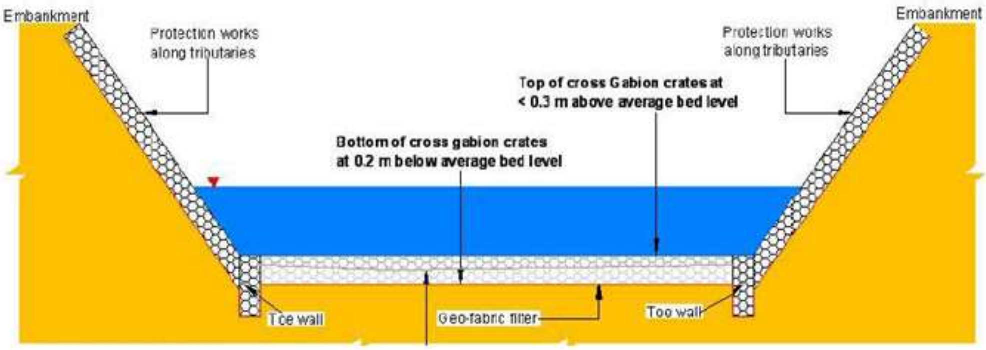
- Longitudinal protection structures.

Installed on river banks parallel to the river course:

Levees or earth fill embankments, Concrete embankments, Revetments and rock riprap, sheet piles, etc

- Other Protection Structures.

Sandbagging, Channel lining, Bamboo piles



Damaged approch road, falling retaining wall and water supply line as on 27-06-2013

Gullies

Gullies are a highly visible form of soil erosion, with steep-sided, incised, drainage lines greater than 30 cm deep. In lay terms, the word 'gully' is often used to describe any drainage line flowing towards a stream. These drainage lines may pass through hill roads and often destroys the layers of the road.

Roads, fences, and firebreaks should be situated in locations that do not readily divert overland runoff and concentrate it to areas that lead to gully erosion. The best place for a road is to follow a ridge line. An examination of satellite imagery in seriously eroded paddocks in the Burdekin catchment shows that graziers being aware of this consistently use ridge lines for access. Roads that run directly up and down the slope will divert or concentrate less runoff than those diagonal to the slope.

Roads should have a profile that does not concentrate overland runoff. Roads that are below normal ground level through constant use or inappropriate maintenance should be re-profiled to a form that does not concentrate overland runoff; alternatively, they should have drainage works incorporated to ensure runoff is dispersed onto stable areas. Associated table drains and mitre drains should have a trapezoidal shape with a flat bottom and not a triangular shape that is more conducive to eroding.

Gully control structures

Weir:

The durability of a weir depends on the construction materials used. Weirs can be made from wire netting, rock, gabions, logs, tyres, concrete, steel sheet piles or hay bales. Strips of suitable vegetation can also be used to act like a pervious weir. Where the vegetation has a relatively short life, the intention is that the weirs will retain some sediment and promote vegetative growth before the weir decays.

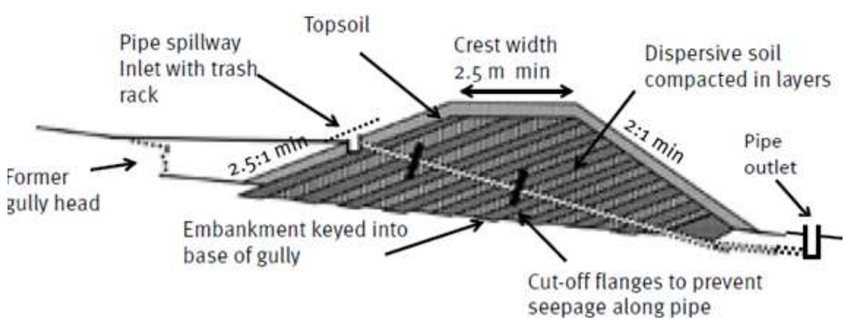
Types of weirs

- Wire netting weirs
- Hay bale weirs
- Rock and gabion weirs
- Tyre-rock weirs
- Concrete and log weirs
- Sand bag weirs

Gully Control Dams

One option for controlling an advancing gully is to 'drown' the gully head by building a dam just downstream. The dam submerges the gully head and the subsequent reservoir of water removes the erosive force of water flowing over the head and prevents it from further erosion.

Due to the cost of building a dam, this option should only be considered if it is an asset other than for gully head control purposes. If the dam spillway requires a chute to return runoff safely to the gully floor then the more practical and lower cost option maybe to simply build the chute to control the gully head.



Chutes

Gully control chutes are formed by battering gully heads to an acceptable slope depending on the method used to stabilize them. As well as for controlling gullies, chutes are used as by-washes in farm dams. They are also used to convey water over steep road batters, to control bed erosion in streams, and for urban developments such as sports fields.

Chutes require some form of energy dissipation at the outlet to help dissipate the energy gained when runoff flows down the chute.

Chute failure often occurs when runoff fails to enter the chute properly. It is critical to control potential leaks and flow bypassing, especially at the chute entrance, and also to ensure suitable side walls contain the flows within the chute.

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